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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXVII.

SESSION 1867-68.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1867-68.

November 12, 1867.

JOHN FOWLER, President,
in the Chair.

No. 1,183 (Supplement). — "Experiments on the Removal of Organic and Inorganic Substances in Water."[1] By EDWARD BYRNE, M. Inst. C.E.

AMONG the many substances that have been recommended as filtering materials, the most prominent, besides charcoal, are those termed magnetic carbide, and silicated carbon. Believing, therefore, that the subjection of these substances to a similar set of experiments to those on charcoal, already described in the Author's original Paper,[2] would be a matter of some interest, both a magnetic carbide and a silicated carbon filter were procured from the agents appointed for their sale.

Having first washed them with distilled water, 8 gallons of pump water were passed through the former, and 12 gallons through the latter, at the rate of 1 gallon in four hours,[3] with the results given in Tables 7 and 8; which exhibit, moreover, the amount of hardness, before and after boiling, as obtained by Dr. Clark's process.

[1] The discussion upon this Paper and its Supplement occupied portions of three evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 547.

[3] In filtering the water, one gallon (occupying four hours in its percolation) a day was passed through the filtering materials. The operation was discontinued on Sundays, as also during the night.—E. B.

TABLE 7.

DESCRIPTION.	Quantities in Grains' weight found in each Gallon.			Degrees of Hardness.		
	Organic.	Inorganic.	Total.	Before Boiling.	After Boiling.	Lost by Boiling.
Original Water . .	16·55	87·52	104·07	51·80	36·50	15·30
Water passed through Filter. 1st gallon . .	14·60	84·35	98·95	50·40	36·30	14·10
2nd „ . .	15·90	84·22	100·12	50·40	36·30	14·10
3rd „ . .	..	..	..	..	..	..
4th „ . .	15·77	85·65	101·42	51·10	36·70	14·40
5th „ . .	..	..	..	..	..	..
6th „ . .	16·78	87·40	104·18	51·80	37·05	14·75
7th „ . .	..	..	..	..	..	..
8th „ . .	16·75	87·37	104·12	51·80	37·05	14·75

TABLE 8.

DESCRIPTION.	Quantities in Grains' weight found in each Gallon.			Degrees of Hardness.		
	Organic.	Inorganic.	Total.	Before Boiling.	After Boiling.	Lost by Boiling.
Original Water . .	16·55	87·52	104·07	51·80	36·50	15·30
Water passed through the Filter. 1st gallon. .	18·75	52·20	70·95	26·60	21·00	5·60
2nd „ . .	18·25	73·70	91·95	42·70	31·80	10·90
3rd „ . .	..	..	..	..	..	..
4th „ . .	15·05	84·00	99·05	50·80	36·30	14·50
5th „ . .	..	..	..	..	..	..
6th „ . .	14·85	86·25	101·10	51·50	36·50	15·00
7th „ . .	..	..	..	..	.	..
8th „ . .	15·70	86·25	101·95	51·80	36·80	15·00
9th „ . .	..	..	..	..	..	..
10th „ . .	15·65	88·79	104·44	52·70	38·20	14·50
11th „ . .	..	..	..	..	..	..
12th „ . .	15·90	90·10	106·00	53·90	39·70	14·20

The excess of organic matter found in the first and second gallons of water that passed through the silicated carbon filter (Table 8) over that contained in the water before filtration, may have been owing to the presence of some extraneous matter in the filtering material that still remained, but which, however, was completely washed out before the passage of the sixth gallon.

From an examination of Table 7 it occurs that, from a gallon of water that at first passed through the magnetic carbide filter, nearly 2 grains of organic and $3\frac{1}{3}$ grains of inorganic matter were

removed; but, after the 5th gallon, there was no removal of either one or the other.

Apparently, the magnetic carbide does not possess the property of softening water unless to a very trifling extent, for even in the 1st gallon the reduction in hardness amounted to little more than $1\frac{1}{2}$ degree, and in the 6th and subsequent gallons that passed through the filter, there was no reduction at all.

According to Table 8, the hardness of the original water, by its passage through the silicated carbon, was reduced at first from nearly 52 degrees to about $26\frac{1}{2}$ degrees; but, after the 7th gallon, there was no gain in this respect—on the contrary, by farther filtration, the water became positively harder.

From the 1st and 2nd gallons of water that passed through this filter, 35·32 and 13·82 grains respectively of inorganic matter were removed; the removal of inorganic matter then became insignificant, and in the 10th and subsequent gallons more inorganic matter was found than was contained in the original water. The removal of organic matter from the 4th, 6th, 8th, 10th, and 12th gallons by filtration amounted to 1·50, 1·70, 0·85, 0·90, and 0·65 grain respectively. What might have been the effect of carrying this set of experiments still farther, may be inferred from the result of subsequent experiments, of which mention will presently be made.

In order to ascertain to what extent these substances would, by disuse, recover their power to remove organic and inorganic impurities from water, the experiments were suspended for a period of two months; after which 4 gallons of a fresh supply of water were passed through the magnetic carbide, and 6 gallons through the silicated carbon filter, with the results shown in Tables 7 A and 8 A.

TABLE 7A.

DESCRIPTION.		Quantities in Grains' weight found in each Gallon.			Degrees of Hardness.
		Organic.	Inorganic.	Total.	
Original Water		12·12	92·40	104·52	51·10
Water passed through Filter.	1st gallon	11·40	91·86	103·26	..
	2nd „	10·55	92·40	102·95	49·35
	3rd „	..	..	..	..
	4th „	11·50	91·55	103·05	49·35

TABLE 8A.

DESCRIPTION.		Quantities in Grains' weight found in each Gallon.			Degrees of Hardness.
		Organic.	Inorganic.	Total.	
Original Water		12·12	92·40	104·52	51·10
Water passed through Filter.	1st gallon	11·80	83·35	95·15	46·90
	2nd „ . . .	7·35	90·25	97·60	48·47
	3rd „	..	..	..	..
	4th „	8·75	89·92	98·67	49·00
	5th „	12·75	88·25	101·00	..
	6th „	13·10	89·05	102·15	50·05

According to Table 7A, less organic matter was found in the second than in the first gallon of water that passed through the magnetic carbide; and according to Table 8A, considerably less organic matter was found in the second and fourth (particularly in the second) gallons than in the first gallon that passed through the silicated carbon filter—an apparent discrepancy which is fully accounted for by the fact that, in each instance, the first gallon of water was passed only once through the filtering material, drop by drop, in the manner explained in the Author's Paper of last Session; whereas, the second and subsequent gallons were passed three times through both of these filters, first, by the slow process just referred to, and afterwards, twice in the ordinary method recommended by the vendors of the filters. The result of this was very striking, especially in the case of the silicated carbon, the effect at once produced being a larger removal of organic matter, but then an almost immediate exhaustion of any removing power these substances may have possessed. In fact, according to Table 8A, the amount of organic matter found in the fifth gallon was more than half a grain, and in the sixth gallon it was nearly one grain, in excess of the quantity contained in the water before filtration.

The water employed in these and the charcoal experiments was taken from the same well, and it was found to vary but little in its composition at the different times of collection. And as the experiments were carried out under similar conditions, a comparison may be fairly made between them.

It appears, then, that the removing power of the magnetic carbide is extremely feeble, whereas the action of the silicated carbon greatly resembles that of animal charcoal. Of the two, animal charcoal is the more efficacious, especially in its property of softening water,

for, by referring to Table 3,[1] it may be seen that the hardness of the original water was reduced from 50½ degrees to less than 9½ degrees, by its passage through the charcoal. This power of softening water, though considerably less afterwards, was so far retained, as to cause a reduction in hardness of nearly 4 degrees in the eleventh and twelfth gallons.

That no inorganic matter was found to be returned by the charcoal may be due to the fact of the experiments not having been carried sufficiently far; but enough has been done to show, that both of these filtering materials (animal charcoal and silicated carbon) quickly lose their power to remove organic matter; and that, if used without frequent rest, they very soon give back a portion of that which had been at first removed, so as to have an injurious effect on the water they may be intended to purify.

To decide, however, the important question, as to whether the organic matter contained in the water, so far as the nitrogen is concerned, had undergone any oxidation by its passage through these substances, the amount of nitrogen in the original water, and in that passed through each filter was determined by the beautiful process which Professor Wanklyn has recently made known. By this, the newest and most delicate test yet discovered, it was found that, for equal quantities of organic impurity, the amount of albuminous matter in the original, and in the filtered waters, was precisely the same, which fact may be fairly considered as a convincing proof, that the organic matter contained in the water had undergone no change by its percolation through these filtering materials.

Filtration, when employed for the removal of matter in mechanical suspension, must ever be considered most valuable; but as a means of removing substances in solution it is manifestly useless.

The foregoing experiments on filtering materials, though made on a small scale, were carried out in a systematic manner, so as to render the deductions therefrom safely applicable to cases of far greater magnitude. They will, it is hoped, serve the purpose of pointing out the danger of depending too much on the system generally of filtration, as well as of exposing the inconsistency of bringing home foul water to undergo a delusive method of purification, instead of adopting the proper and only satisfactory plan, of procuring water which is itself naturally pure.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 551.

Dr. Letheby stated, that the results obtained by the Author of the Paper did not accord with his own experience and observation over many years; and if it were not that, in the account of the experiments, there was a means of explaining the apparent discrepancies, he should regard them as most remarkable. The water was singularly hard, and did not at all represent what was usually furnished to a community for domestic purposes; for he had never found water supplied by a public company containing from 99 to 109 grains of solid matter per imperial gallon, and with a hardness of about 56 degrees. It also appeared that nearly 11 grains of this was organic matter. But he would ask how that had been determined? Because if it had been estimated by the process of incineration, it afforded no evidence whatever of the existence of such a quantity of organic matter in the water, or of the action of animal charcoal upon it.

Mr. Byrne said, the method he employed was the one to which exception was taken; but it was that which was adopted by experienced chemists, and allowed to be as good as any other at present known.

Dr. Letheby contended that this opinion was erroneous, for the process was not relied upon by chemists. He thought, also, the proportion of oxygen required to oxidize the organic matter, as shown in Table 2, Column 5, proved that there could not have been more than a trace of it in the water. He would say, therefore, that the numbers in Column 2 of that Table were no criterion of the quantity of organic matter present; and that the experiments were not to be relied on.

He agreed with the conclusions of the Author, that if animal charcoal only possessed the power of physically absorbing organic matter, it would give it out again by the process of diffusion when more water went through it. But the action of animal charcoal was of another kind,—it had the power of bringing the oxygen dissolved in the water into chemical union with organic matter, and so of destroying it; this was especially the case when the organic matter was in a state of decay, and in an unwholesome condition. An essential element, therefore, of this change was the presence of oxygen; but the well water in question, although charged with carbonic acid, contained little or no oxygen; for such water rarely, if ever, contained enough free oxygen to effect oxidation of the organic matter; and that explained what would otherwise be a difficult thing to understand, viz., how any water containing a notable proportion of organic matter could pass through animal charcoal without having its organic matter absorbed and oxidized. Again, he had found from his own experiments, that a certain time was required for the oxidation of organic matter by charcoal; that, in fact, the

water must be in contact with the charcoal for 1 minute at least, in order to effect a marked purification.

Now, a cubic foot of animal charcoal, weighing from 50 lbs. to 52 lbs., held within its pores four gallons of water; unless, therefore, the powers of the charcoal were unduly strained, water could not be filtered through it with greater rapidity than four gallons per minute per cubic foot. He did not gather from the Paper at what rate the water, in these experiments, had passed through the filter?

Mr. Byrne replied, at the rate of 1 gallon in four hours, and that the charcoal was 5 inches in thickness.

Dr. Letheby: The question of thickness was of little moment: it was the quantity of charcoal to the quantity of water that was most concerned in the result. The time of contact of the water with the charcoal in the experiment given would then be $2\frac{1}{2}$ minutes, or about the time that animal charcoal would require to effect anything like proper oxidation; but in practice it was found that water could not be forced through a filter holding 80 lbs. of charcoal, so as to be effectually purified, at a greater rate than 400 gallons per day. That was the rate at which the Water Purifying Company guaranteed the action of their filters; and in a working day of fifteen hours the water would be in contact with the charcoal 6·7 minutes on the average. He had used filters of this description for more than a year, and at the end of that time he found that the water, when tested by permanganate of potash, contained little or no organic matter. His own experience, therefore, did not accord with the results brought under the notice of the Institution; and but for the circumstance that the water used in these experiments was of an exceptional character, he should have been unable to reconcile these apparent contradictions. But, although animal charcoal was capable of effecting the removal of organic matter from water, he was not inclined to recommend its use in the manner and to the extent lately suggested. The proposal to filter all the water supplied to the Metropolis through animal charcoal at the sources of supply did not appear to be either a useful or a practicable measure. He did not think $1\frac{1}{2}$ ton of charcoal per million gallons of water, or even 3 tons or 4 tons, as had been stated, would be sufficient to effect any great improvement in the water, for the time of contact would only be from 12 seconds to about a minute. While, then, he did not believe that charcoal could be used in such a manner, yet when applied in the houses where the water was used, and which was for many obvious reasons most convenient, his experience went to show it was not only able effectually to remove and oxidize organic matter, but was unquestionably one of the best safeguards in the hands of the public against those mischiefs which might arise from the presence of organic impurities in water.

Dr. Frankland remarked, that the results of the Author's investigations differed so entirely from those he had obtained himself in similar experiments, that at first he could not at all reconcile the differences. On reading the Paper through, however, there remained no doubt on his mind as to the cause of the discrepancy. The Author had, in fact, evidently been operating upon water which contained only a very small quantity of organic matter, but a large proportion of those ingredients which were derived from the previous oxidation of the organic matters in sewage, viz., nitrates and nitrites, and these gave off a considerable quantity of volatile matter when the solid residue was ignited. The loss by ignition, thus obtained, was shown in the columns of the Tables headed "Organic Matter," but which ought to have been entitled "Organic and other volatile Matter;" as from the Author's examination of the water by the permanganate test, there could be no doubt that three-fourths, or perhaps even four-fifths, of that matter which was represented as organic consisted in reality of the inorganic constituents of nitrates and nitrites. What had been proved was, that animal charcoal, when first applied to water of this character, would abstract from it a large quantity of the nitrates and nitrites along with other salts present in water. But the Author left untouched the question, whether animal charcoal did or did not remove organic matter from water; far less had it been proved that the organic matter was first removed from and then restored to the water. He had himself for some time been engaged in experiments on this subject, and would state a few of the results obtained with animal charcoal as a filtering medium applied to the New River water. An animal charcoal filter, through which the whole of the water used for domestic purposes was passed, had been fixed in his house eighteen months ago: the water passing through it was examined a few days after, when he found, on a comparative analysis of the water, that the amount of solid constituents contained in it was respectively 17·78 grains per gallon before filtration, and 11·60 grains per gallon after filtration. The organic and other volatile matter present in the water before filtration was 0·37 grain per gallon. This was reduced by the animal charcoal to 0·15 grain. The oxygen removed from permanganate of potash by the organic matter was 0·02 grain per gallon before, and 0·005 grain per gallon after filtration. The water was examined again in June, a month after the filter had been in operation, during which the water passed through at the rate of about forty gallons per day. The results were:—

	Before Filtration.	After Filtration.
Total solid residue	15·08 grains	13·70 grains
Organic and other volatile matter . .	0·64 „	0·21 „
Oxygen removed from permanganate .	0·0176 „	0·005 „

Thus, after the lapse of a month, the charcoal was still removing a perceptible quantity of the solid constituents, while the organic and other volatile matter was being removed even in larger quantity than before, inasmuch as it amounted before filtration to 0·64 grain, and after filtration to only 0·21 grain: while the oxygen abstracted from permanganate of potash by the organic matter was reduced from 0·0176 grain to 0·005 grain—less than one-third of the amount previous to filtration.

The experiments were continued in July, with similar results; but the action upon the total solid constituents became less marked each month, although the action upon the organic and other volatile matter was maintained up to the time the water was last examined. The numbers obtained in July were—

	Before Filtration.	After Filtration.
Total solid residue	14·41 grains	13·71 grains
Organic and other volatile matter . .	0·41 „	0·08 „
Oxygen removed from permanganate .	0·0148 „	0·005 „

In September, which was four months after the fixing of the filter, and when about 5,000 gallons had passed through it, an appreciable though very small proportion of the solids was removed, and the organic and other volatile matter, to the extent of nearly one-half, the numbers being—

	Before Filtration.	After Filtration.
Total solid residue	14·26 grains	13·80 grains
Organic and other volatile matter . .	0·55 „	0·30 „
Oxygen removed from permanganate .	0·009 „	0·0045 „

Hence his own experiments on this subject led to totally different conclusions from those of the Author, with regard to the action of animal charcoal upon the organic matter in water. On the other hand, his experiments with vegetable charcoal agreed with those of Mr. Byrne in giving negative results. This kind of charcoal was found to be absolutely inert in its action on organic matter in water.

With regard to the purification of water by filtration through animal charcoal on a large scale, his views did not coincide with the opinion just expressed. He had passed the water supplied to London by the Grand Junction Company through a stratum of animal charcoal 3 feet thick, at the rate of more than forty-one thousand gallons per square foot per day of twenty-four hours, under a head of water of 30 feet. The charcoal was in granules, like coarse sawdust, and was maintained in its place by a perforated plate at the top of the stratum. At that rate rather more than one-half of the organic matter in the water was removed; but on reducing the rate of the passage down to one-half, one-fourth, or one-tenth, the proportion removed was scarcely increased.

There appeared to be two kinds of organic matter in water; one was readily attacked by animal charcoal, whilst the other required an amount of contact with the charcoal which in practice could not be afforded. He did not agree that the filtration of the water-supply of a town through animal charcoal was impracticable. He thought, on the contrary, it was a process that could be readily applied, and that it ought to be carried out by the Metropolitan Water Companies, as it would remove from such water as was supplied to London about one-half of the organic matter contained therein.

Mr. J. F. Bateman remarked, that a good sand filter would allow water to pass vertically at the rate of about 6 inches per hour, or 12 feet per twenty-four hours.

Dr. Frankland said, it was a misnomer to apply the term "filtration" to this operation with animal charcoal: it was rather a passing through. The interstices were so large that the process could scarcely be called "filtration."

Mr. T. Spencer asked Dr. Frankland by what means he ascertained the amount of organic matter present in the water in the experiments he had made, whether by incineration or by permanganate of potash?

Dr. Frankland had determined the amount of organic matter by both processes, though he had since expressed his disbelief in their accuracy for determining the actual amount of organic matter, as the results of his experiments by the permanganate method of testing and by the incineration process did not agree. But the question of the removal of organic matter by animal charcoal did not rest exclusively upon either of those imperfect methods. He had, in fact, recently repeated these experiments with animal charcoal and the New River water, and had determined the carbon in the organic matter directly by organic analysis. By this he found that the organic matter in the New River water before filtration contained 0·217 part of carbon in 100,000 parts of water; whilst after filtration it contained 0·071 part; so that only one-third of the organic carbon was retained in the water after filtration through animal charcoal. The results of this latter analysis, as regarded the abstraction of mineral salts and other constituents, and the alteration of the hardness of the water, resembled those he had already mentioned, in which respect he agreed with the Author, as also in his recommendation that all purifying processes should be regarded as only temporary measures, pending the substitution of a pure for a contaminated supply.

Mr. T. Spencer asserted, that the results of testing the quantity of organic matter in water by the two methods now in ordinary use, viz., incineration and the permanganate process, could not agree, especially if the water contained iron—which nearly all

waters did, more or less. The permanganate of potash method was, in the first instance, greatly lauded, as an easy mode of getting at difficult results; hence many persons who were not chemists adopted it. Consequently large quantities of organic matter were set down as being found in water, but which older chemists, who had gone over the ground before, not only did not find, but knew could not exist. He agreed that the large amount of organic matter, said to be found by the Author in potable water, was really an impossibility, though such would appear to be so in regard to water containing iron, if tested with the permanganate of potash. He had himself, in the course of his practice, analysed specimens of water from most districts in the kingdom, and had never heard of any reliable chemist who had found organic matter existing in a town supply even to the amount of 7 grains per gallon. Therefore he held that there had been some mistake, with regard to the quantity of organic matter set forth in the Tables, probably due to this cause.

With regard to the subject of depriving water of matters it held in solution, the main thing he had sought for, ever since his attention had been directed to the subject, had been to get rid of organic matter only. At the time, such a search was deemed by most chemists to be impracticable. Though some few conceived it possible, by others it was considered impossible, to deprive water of its organic matter without substituting something else in its place. He need hardly say, that when anything was taken out of solution, as a rule, something else had to be supplied to fill up, as it were, the space previously occupied by the substance taken out. He did not say this was strictly so in all possible cases, but it was a practical axiom, with which he thought every chemist would agree. It was not unreasonably supposed, that charcoal had the power of destroying organic matter, because in many instances it partially decolourized the water. It thus came to be recommended as capable of freeing water from organic matter. No doubt charcoal did decolourize water for an hour or two; but when this was observed, it was not ascertained whether the colouring matter was retained in the pores of the charcoal, or destroyed. The Author had shown that the organic matter originally taken from the water in his first experiments was, after a short time, given back to it from the charcoal, by the fact of its existing in the water in greater abundance than it did at first. In other words, some of the water contained more organic matter after it had passed through the filter than it did before filtration. Assuming, therefore, that the experiments were in this respect correct, it showed that the organic matter taken from the water in the first instance was only secreted in the pores of the charcoal, and that when they became full it had no power to take any more, but, on

the contrary, it gave back what it had already taken. The results of the experiments entirely agreed with those repeatedly made by himself. Similar experiments, with like results, were made for Mr. Telford for his report to the Government in the year 1830. In short, the same ground of experiment had been gone over frequently; as it was too much the habit in such cases for one generation to forget what had been done by the previous one, and because the results were negative, they were put down as not having been made. In the abstract of the report referred to, it was merely stated that no substance was calculated to deprive water of any matter it held in solution; but the details of this report showed, that the organic matter was left in the charcoal, just as the Author had found it in his experiments.

As to the power of charcoal and of another substance to deprive water, by filtration, of inorganic matter, according to the results of these experiments, it was found that, at first, the water after filtration not only contained slightly less organic matter, but also less inorganic matter. Now, he had no doubt that, up to a certain point, that was so, as he had himself often found it; but it would be a great calamity indeed, as far as filtration of water went, if such were to continue even for some hours. It was quite true that charcoal, when new, took a portion of the carbonate of lime or magnesia out of the water, though to a small extent only. But supposing, however, it continued to do so even for an hour, the filter would be stopped, by its interstices becoming filled up with chalk. In a word, if charcoal, or so-called silicated carbon, or magnetic carbide, continued to take inorganic matters out of water, all these filters would be stopped by a few hours' use. Therefore, with regard to magnetic carbide, or charcoal, or any substance which thus took hardening matters out of water, the whole of the pores would in time be closed, when filtration would cease. Not long ago a letter appeared in 'The Times,' stating that a charcoal filter had been erected at the east of London, by which the New River Company's water was reduced several degrees in hardness, and the organic matter was removed. Now, as he believed both results to be impossible, or, at all events, that neither could continue, he sent for some of the water, and ascertained that it was of precisely the same degree of hardness he had found it to be many years before. He had taken the facts from one of the engineering journals; but as it was suggested that he might after all have been wrong, he tested a fresh sample of the water, and with the same results as at first: not only was there the ordinary quantity of carbonates and of organic matter, but the latter was, if anything, slightly increased.

With regard to the comparative experiments recently made by the Author on silicated carbon and magnetic carbide, every

chemist knew there was no such substance as silicated carbon. He had always insisted upon these filters, when brought forward for public experiment, being opened. He had done so once at the Society of Arts, and on putting a magnet into the interior of a silicated carbon filter, he found the material in it contained a visible percentage of magnetic carbide. The 'Lancet' Sanitary Commissioner, who had also lately made a comparative examination of water filters, found that the magnetic carbide practically took all the organic matter out of water, leaving only the 500th part of a grain in the gallon. In this case also he insisted that the filters should be opened after the experiments, when it was admitted that there was something very much like magnetic carbide in the silicated carbon filter, and that no doubt the whole action of the filter rested upon that material. Therefore the results given by the Author, in regard to the silicated carbon filter, ought to be rejected, unless it had been opened, and a magnet applied to its contents, when if it attracted any substance, it was magnetic carbide beyond all doubt, and to this the filter owed any purifying power it possessed.

Professor Wanklyn said, as to the process of filtration removing nitrogenous matters from water, that Mr. Chapman, Mr. Smith, and himself, had made an examination of the water at Hampton, where one of the Water Companies took its supply, and they found that there were about 15 parts of albumenoid ammonia in every 100,000,000 parts of water. They then took some of the water after it had been filtered by the Company, and found only 5 or 6 parts of the same remaining in it. This showed that the filtration effected by the Company was capable of removing two-thirds of the impurities from the water, while he had heard that they were removed only to the extent of one-half by the carbon filter. It appeared to him that there was no need of the carbon filter on a large scale; for this was a larger removal of impurities than the advocates of the carbon filter claimed. With regard to the analysis of the water given by the Author, all chemists must agree that the Tables could not be relied on, although the determination of the amount of permanganate destroyed might have a relative value. That which was called organic matter was probably carbonic acid and hydrochloric acid. The amount of permanganate destroyed was no indication of the amount of organic matter. Some organic matters took up a great quantity of permanganate, and others very little. The forms of albumen most to be dreaded would probably take very little permanganate.

Mr. Spencer wished to explain, that the permanganate of potash test acted by oxidizing the organic matter. Now, wherever there was iron in water—and there were few waters that did not contain some—the iron existed as a protocarbonate, that was, a carbonate

of iron dissolved by an extra atom of carbonic acid, precisely in the way chalk was taken up and held in solution by water. Suppose a small amount of sulphate of lime or magnesia were added to distilled water, and that a protosalt of iron, even to the extent of half a grain to a gallon, was added also: that water, by testing it in the usual manner with permanganate, would indicate several grains of organic matter. Therefore, with permanganate of potash organic matter was invariably found, whether it existed or not. He, along with others, had sent to chemists samples of distilled water, to which some sulphates were added, and a quarter of a grain of a protosalt of iron, but without a particle of organic matter; and the water had been returned in the report of the analysis as containing some grains of organic matter per gallon. He thought the permanganate test, as a means of detecting organic matter in water, ought now to be discarded.

Mr. Ernest T. Chapman remarked, that he had made a considerable number of experiments with animal charcoal on water containing nitrogenous organic matter, and that the nitrogen of the organic matter was determined by the process adopted by Professor Wanklyn, Mr. Smith, and himself. He was not contented with observing that the organic matter disappeared from the water. He assumed that either the nitrogenous matter must be oxidized, or that it would be found hanging about the charcoal; as no doubt could exist that the amount was diminished by filtration through animal charcoal. He agitated some charcoal in water, and extracted from the charcoal the same quantity of nitrogenous organic matter as had been previously removed from the water. It was evident that this action did not consist in bringing together the free oxygen dissolved in the water and the organic matter, and consequently in converting the latter into carbonic acid, ammonia, and nitric acid. In another experiment he deprived the water of oxygen by treating it with protochloride of tin, and on agitating this water with animal charcoal he found nearly the same reduction in the amount of nitrogenous organic matter, showing that there was no oxidation; and he again extracted the same amount of nitrogenous organic matter from the charcoal that had been removed by it from the water. Animal charcoal was not alone in this peculiar property. In the process known as Dr. Clark's, the softening of the water was effected by the precipitation of the carbonate of lime it contained. If water which had been filtered through sand were softened by Dr. Clark's process, it would be found that at least a portion of the nitrogenous organic matter existing in the filtered water would be removed, and the same amount of organic matter could be extracted from the chalk as had been removed from the water. He had passed water through animal charcoal, and found a reduction in the amount of organic matter; but after a few weeks' use the charcoal was im-

pregnated with organic matter to such an extent as to be useless. Even the agitation of finely divided silica would remove traces of organic matter in water; and no doubt if he had used fine silica he could practically have removed as much matter from the water as by the use of charcoal.

The point he chiefly dwelt upon was, that in filtration by charcoal the organic matter was not oxidized, but was mechanically retained by the charcoal. If that were the case, the question of purifying large volumes of water by charcoal resolved itself into the use of a sufficiently large quantity of charcoal to remove the objectionable matter, and the substitution of fresh charcoal, for after a little while the organic matter contained in it would putrefy, and be dissolved by the water. It was said to be an unfortunate chemical fact, that putrescible nitrogenous matter could not be distinguished from that which was not putrescible; but he believed nitrogenous organic matters of all kinds were putrescible. If water containing any nitrogenous organic matter, together with nitrates and nitrites and carbonic acid, were exposed to the sun, it would acquire a green colour: even in filtered water a green slime would form, and in time give forth an offensive odour; and, when dealing with large volumes of water, that was extremely objectionable in every point of view. What had to be avoided in water was not nitrogenous organic matter of one kind only, but organic matter of all kinds; and until it was established that there were some nitrogenous organic matters which would not putrefy if exposed to the action of air and heat, the only safe course was to avoid all kinds of organic nitrogenous matters in the water used for domestic purposes.

Mr. Hawksley,—Vice President,—was surprised at the statement that water could be filtered through charcoal in mass at the rate of forty-one thousand gallons per day per square foot of area of the charcoal. He fancied there must be an error of calculation; for if it were not so, as water passed through a main pipe at the rate of from 2 feet to $2\frac{1}{2}$ feet per second, to filter all the water required by a large town, it would be only necessary to quadruple the diameter of the main pipe at the end, whatever might be its size, and to fill it for 5 feet in depth with a mass of charcoal. That was perfectly inexplicable, and if it were viewed in another aspect it would be equally so. It appeared from the same experiment, that a foot of charcoal would filter about five hundred times as much water as a foot of sand. But he did not think this subject had as yet been treated in a practical manner. The chemists had given valuable information; but it did not enable them, as engineers, to make waterworks better. Attempts should be made to understand how it was that filters operated; whether the charcoal was necessary or unnecessary; and whether the common and ordinary sand filtration

was sufficient for the purpose. This subject had engaged his attention for more than twenty years; and he had acquired some knowledge of the facts, though it might be impossible, at present, to assign reasons for them. He thought that sand filters operated not only mechanically, but also chemically, and that the chemical changes depended very much upon the particular state of the organic matter in the water, and on the admission of the free oxygen of the atmosphere. The sand filter cleared the water mechanically by the agency of the well-known principle of the attraction of aggregation. When the water descended slowly through the filter, the minute particles of matter suspended in it were attracted by the facets of the sand and adhered there, and the water became clear; and that operation was carried on so rapidly, that scarcely in any filter did the water remain foul for more than a few inches from its surface; and a bed of sand 12 inches thick was just as effective as one of 2 feet or 3 feet. The sand filter also operated chemically, for it actually destroyed organic matter, and deprived water, in which lime was held in solution by the excess of carbonic acid, of part of the chalk, thereby softening the water. He did not lay much stress upon its action upon the chalk, because in that respect, though the operation was similar, it was not equal to that of the carbide filter, which he knew, from experience, to be exceedingly useful, and performed good service in the destruction of organic matter; as, indeed, charcoal did for a time, and all substances which had the power of what was called revivification. In point of fact, any substances which attracted oxygen to the surface and gave it back again to the organic matter, destroyed that organic matter, and rendered the water pure. That was, to some extent, effected by the sand filter; and to a larger extent by the carbide filter, but only under particular circumstances. Hence, although he thought the latter was useful in certain cases, yet for water-works he considered the ordinary sand filter the best. For the filtration of water for the table, he thought there was no filter which was better than one or other of the two filters to which he had referred, viz., either the combined carbon and sand filter, or the filter of Mr. Spencer. But to show that, after all, none of these substances were absolutely necessary, either for the destruction of organic matter in water, or for clearing it from suspended matter, he would mention a peculiar stone found in Derbyshire, which, he recollected, had been used for filtering purposes forty years or fifty years ago. It resembled fire-stone, and allowed water to pass through it, in one respect slowly, but in this respect tolerably rapidly, and absolutely freed the water from organic matter, at the same time that the impurities in suspension were taken out. That stone would continue to do this for years, and perhaps for centuries, if it were only brushed on the surface, so as to keep the pores open.

With regard to what had been said of nitrogenous substances, there was something very important yet to be learned. It had never been proved that they were injurious to health, excepting they were in large quantities, such quantities, in fact, as did not obtain in any water-supply to towns; and it was uncertain whether assertions of their existence were always reliable. The methods employed to ascertain this were by no means certain; and even if they were, the results professedly obtained were so small in amount, that the substances found might be considered immaterial, and practically harmless. He had studied this subject in a practical way, as an engineer, and he had come to the conclusion that a great deal of nonsense was talked about organic matter in water; in fact, in the course of the discussion an instance had been given of its being found where it did not exist. It would not be nice to adduce instances of human beings liking such water; but where did the horse or the cow go for water but to the horse-pond, which was full of this organic matter? It was brown and foul, so that no human being would touch it, but the horse and the cow went to it by choice, and suffered no harm whatever. Although it was undoubtedly the duty of Water Companies to supply water to the people as pure as it was possible to obtain it, yet the public need not, after the Companies had done their best, be at all afraid of the water they delivered.

But there was something remarkable which he had to show, and that was two bottles of the same water drawn from a deep well far out in the country, and from a depth of 400 feet. The water in one had been filtered through charcoal: that in the other had not been filtered at all. The two bottles had stood upon his chimneypiece, side by side, for three years, and they had both been similarly exposed to light and temperature. The one which had not been filtered through charcoal was as bright as when it came out of the well; but the other, which had been filtered through charcoal, remained bright for twelve months, and then it began to turn a dingy yellow, and had become more and more coloured up to the present time; and he had kept it as a curiosity, watching what happened to it, till now it had assumed the appearance of weak sherry. He could not tell what had caused this change, as he had not examined the water, but he supposed something injurious had been taken out of the animal charcoal; and he was not, therefore, in favour of the use of animal charcoal, especially when it was new.

Mr. Spencer said, eighteen years ago, some experiments had been made at the Rivington Waterworks with the Derbyshire stone, to which reference had been made, when Mr. Hawksley succeeded in 'doubling-up' that stone as a filter in five minutes' use. The same result was also observed with the same stone at

Nottingham, though in that case the result was not so rapid, as the pressure was less.

Dr. FRANKLAND remarked, through the Secretary, that although he had frequently filtered water through animal charcoal at a much higher rate than that previously mentioned, he had nevertheless determined to repeat some of the experiments. He therefore fitted up a tube filter, and passed the Grand Junction Company's water through it, both upwards and downwards. The filter resembled as nearly as possible the one used in his former experiments, except that the stratum of charcoal was 2 inches thinner. The glass tube was 36 inches long, 1·3 inch internal diameter at one end, and 1·44 inch at the other, so that the mean sectional area was 1·474 square inch: this contained a stratum of animal charcoal 34 inches thick. Three experiments were made on upward, and three on downward filtration. The head of water was 19½ feet in the upward filtration, whilst in the downward filtration it was 22½ feet. The following were the results obtained:—

I. Upward filtration: water moving from the narrow to the wide end of the tube.

	Volume of Water delivered per minute.	Rate per square foot per 24 hours.
First Experiment	0·578 gallon	81,312 gallons.
Second ditto	0·609 „	85,673 „
Third ditto	0·636 „	89,471 „

II. Downward filtration: water moving from the wide to the narrow end of the tube.

	Volume of Water delivered per minute.	Rate per square foot per 24 hours.
First Experiment	0·645 gallon	90,734 gallons.
Second ditto	0·638 „	89,752 „
Third ditto	0·600 „	84,407 „

It was thus evident that the rate of filtration mentioned by him, so far from being impossible, was not one-half of the speed at which water could be passed through animal charcoal. Hence it was to be hoped that objections on this score would no longer be urged against the employment of a process of purification at once simple, inexpensive, and, so far as regarded the removal of organic matter in solution, the most efficacious with which he was acquainted.

It would be perceived that the experiments on upward filtration exhibited a constantly increasing flow in each successive trial, while in the experiments on downward filtration the rate was gradually reduced. This phenomenon appeared to him to indicate that,

although in these trials the downward was, on the average, more rapid than the upward filtration, yet, in the long run, the latter would have a considerable advantage.

Mr. Hawksley,—Vice President,—did not dispute that water might be made to run through charcoal at the rate just stated; and if a pressure of 19½ feet in the one case, and of 22½ feet in the other, were applied, he thought the rate might have been even greater. But the question was whether any satisfactory chemical effect could be produced on the water, and whether it could be produced from day to day over a long period of time? He ventured to say that was impossible. In this particular experiment the water was made to pass more than a thousand times as rapidly as under the ordinary process of filtration. At the slow rate at which water usually flowed through main pipes, it would require a pipe 12 inches in diameter, with a constant flow of water, to supply a service reservoir for a city of forty thousand inhabitants; and if the results of the experiments were to be accepted, to establish an effectual filter it would be only necessary to add to the end of such a main, a piece of pipe a few feet long and 4 feet in diameter, and to fill it with charcoal; but this was contrary to all experience.

Plate I., Figs. 1—4, represented the filter-beds and the pure-water tank of the Leicester Waterworks. Before filtration, the water held in suspension a perceptible quantity of muddy matter, and was also sensibly brown from a little peat and other organic matter found on the surface of the water-shed from which the water was derived; after filtration the water was completely freed from matters in suspension, and was generally deprived of colouring matter, though in the worst seasons there was sometimes a slight discoloration. Now these were sand filters, and the plan of filtration, though simple, was as serviceable as any system of filtration with which he was acquainted. The water was brought from a large storage reservoir, about 40 acres in extent, into the filter-beds, of which there were four, in separate channels, so that either filter could be taken up and cleaned without disturbing the action of the others; it then passed downwards through the sand and through successive strata of gravel into the drains, and from these by means of pipes into the central pure-water tank. In forming a filter-bed care should be taken that the sand was not fine; otherwise, as was too often the case, the filter would speedily be choked. Coarse granular and silicious sand, resembling small diamonds, was the proper sand for filters. It attracted the particles of matter suspended in the water just as well as the finest sand; it did not readily become obstructed, and it was easy to clean; while fine sand was very difficult to clean. After the sand was cleaned it might be laid down again, and so from time to time over

a long course of years. If muddy water were put into a glass with vertical sides it would be found that the suspended matter not only went to the bottom but discoloured the sides; this arose from the adhesion of the particles of matter suspended in the water within the range of the attraction of the glass. So, in the filter-beds, the water percolated through the sand, and in going through the small passages the suspended matter came within the range of the attraction of the particles of sand and adhered to them, leaving the water clear. In order to make a filter successful it ought to be under the least possible amount of pressure, and not a pressure of 20 feet or 30 feet. To prevent the pressure exceeding a certain limited extent the pipes delivered themselves into a pipe which stood up in the pure-water tank within 2 feet of the surface (Fig. 4). By this contrivance there never could be more than 2 feet of pressure upon the sand, and the water was obliged to go through at a slow rate, amounting to about six hundred or seven hundred gallons per day per square yard of surface. The effect was to produce a water not only free from suspended matter, but which was to a great extent operated upon chemically; he did not mean to the full extent, because unless reagents of some kind or other were employed all the organic matter could not be removed; but there was a very sensible diminution of the organic matter.

In the London waterworks filtration was, in general, well carried out; and the water supply was excellent for general use: it was palatable, free from organic matter, all but in infinitesimal proportion, and was well aërated; and, for all practical purposes, was as good as could be supplied to any city where there were not special manufacturing uses for it.

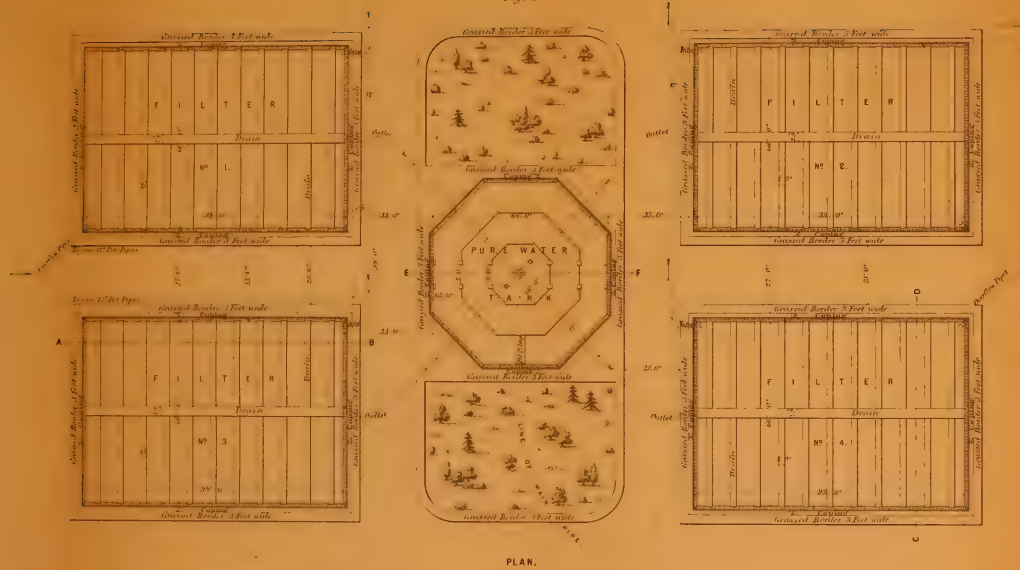
Soft-water supplies were usually situated near the coal-fields in the northern part of England, and consequently not only by reason of the produce of coal, but also on account of the solvent power of the water and its freedom from what had been improperly called organic impurities, manufacturers were found to resort there. They did not go there because soft water was beneficial to health, but because it was suitable for manufacturing purposes. A different conclusion must, in all cases, be drawn with regard to towns where there was dyeing, or bleaching, or calico-printing, or the manufacture of wool, or anything of that kind, and towns where water had to be supplied mainly if not wholly for domestic use. In the one case it was undoubtedly better to resort to mountainous districts, notwithstanding that the water might be discoloured, to obtain good water for manufacturing purposes. But in those cases where manufactures did not abound, and where the water was used for other purposes, it would be folly to bring in discoloured water when clear water could be had, as such a course always gave rise to violent contentions.

FILTRATION OF WATER.

LEICESTER WATERWORKS.

PLATE I

Fig: 1.

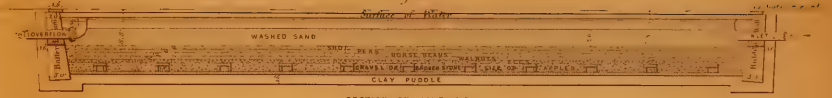


PLAN.

Scale for Plan 40 Feet = 1 Inch

Feet 10 0 20 40 80 120 160 200 Feet

Fig 2

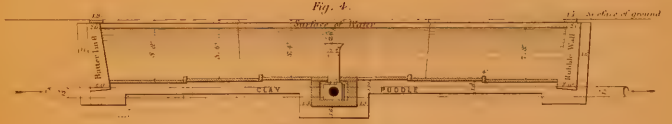


SECTION ON LINE A B.

Fig: 3.

SECTION ON LINE C D.

Fig: 4.



SECTION ON LINE E F.

Scale for Sections 16 Feet = 1 Inch

Feet 10 0 4 8 16 24 32 40 Feet

With regard to the value of soft waters for effecting a saving in soap and tea, but little water was used for detergent purposes, excepting in manufacturing towns, and only in some of them. In London not one-twentieth of the water distributed to the public was used for detergent purposes; therefore it would be inexpedient to sacrifice the clear and agreeable water, which looked unobjectionable on the table, for that which might save a small quantity of soap.

Reverting more particularly to the subject of the Paper, he would observe that chemical analysis was confessedly a good deal in fault with regard to the assessment of the amount of organic matter in water. The processes used were also those which altered the character of the organic matter; and the chemist did not pretend to discover by the process of analysis the state in which that small quantity of organic matter, which he professed to detect in water, existed. He thought that chemical facts, and all facts within the range of observation, proved that it was impossible that this infinitesimal quantity of so-called organic matter, the character of which was still unknown, could be injurious to health. He considered that so large was the quantity of oxygen existing in rivers and in springs, that under no circumstances could it be possible for nitrogenous matters to exist in them in an injurious state. The names used on these occasions were perpetually being changed. Organic matter was first called by one name, and then by another, and every new name was supposed to indicate a new evil to be overcome; but in point of fact these albuminous matters were old things under new names, and when they were spoken of as being dangerous it was merely begging the question. No one objected to eggs for breakfast, and yet there was ten thousand times more albuminous matter in an egg than there was in all the water drank by a person in a year. And as to animalcules in water, which were said to be so dangerous, there was far more matter of a similar kind in a live oyster. Horrors were painted which had no existence; and it was against these imaginary horrors that he stood up to raise his voice. At the same time he considered it to be the duty of the engineer to supply the public with water in as pure and unobjectionable a state as possible; but, however pure, it would be impossible to supply it in such a state that the modern chemist could not, if he pleased, find some fault with it. The inhabitants of towns supplied with pure mountain water were said to enjoy good health; but it happened that the very reverse was markedly the fact, not in small but in large percentages. Yet this was not because of the water; it arose from the social condition of the populations. In Manchester, Liverpool, Glasgow, and other places supplied with soft waters, both from the nature of the occupations of the people and from the rapidity with which they bred and introduced young life, which was subject to great mortality, the ratio of mortality appeared

unduly heavy. While, according to the reports of the Registrar General, in Sussex and on the east coast of England, where there were no manufactures, and the increase of population was small, the people were long-lived.

Mr. Alfred Smee denied that a small quantity of organic matter in water was immaterial. A small quantity of small-pox matter would infect a large number of persons, and a less quantity of scarlet-fever poison was required to propagate that disease. There were many other poisons communicated by means so subtle that the material agency by which the poison was carried from one person to another had never been discovered, whilst there was distinct evidence that it was so carried. When the great cholera epidemic struck the neighbourhood of Golden Square, Dr. Snow visited every house that was attacked, and in each instance traced the mortality to the use of the water from the pump in Broad Street. He thereupon went to the vestry, declaring that the remedy against cholera in that district was to chain up the pump. When the authorities heard of the simple means he recommended, they were inclined to treat the suggestion with ridicule; but they argued it could do no harm, if it did no good, and when they chained the pump-handle the mortality decreased.

It had been alleged that cows and farm horses preferred to drink water contaminated by sewage, and he could state, of his own knowledge, that if those animals had the choice of clear water and of foul water, they would leave the pure water for the latter. For instance, the water which flowed through Croydon had been habitually taken by some cows. These were attacked with the rinderpest, whilst those around the district did not suffer from it. Nevertheless, it was not only cows but mankind who, in many cases, preferred this particular class of water. Churchyard pumps were resorted to in preference to others; there was something in the taste of the water, probably from the salt it contained, that excited the palate and induced people to drink it in preference to pure water. On the last epidemic visitation of cholera, he recommended the authorities to take off the handle of the pump over the old Roman well in the Bank of England. That well, which was a celebrated one, was derived originally from the gravel; but now there was reason to believe it was supplied from leakages beneath the urinals. It appeared that, when the handle was taken off, some of the people of distinction in the locality begged that they might not be deprived of that water, as it was the only drinking water they enjoyed. He had no hesitation in saying that where tainted water was supplied to the public it was a matter of great moment, and that whenever an epidemic appeared the community must be cautious to do all they could to avoid the use of it.

The next part of the question was the character of the organic matter. This, if like the white of eggs, or a basin of soup, was harmless; but let the soup or white of eggs get into a putrefactive state, and the operation, like the leaven of bread, would communicate its taint far and wide. It was matter in the act of change, and it set up change in contiguous organic matter. The damage done to individuals of every species by the excretæ of the same species was generally recognized by the medical profession; and the doctrine of the harmlessness of changing organic matter was universally regarded as a medical heresy.

Now, what did Boards of Health frequently do? He would rather call them, in many cases, Boards of Death. The Croydon Board of Health formerly took the water which naturally flowed into the stream, passed it through the town and the water-closets, and then poured it in at the top of the River Wandle to poison every person living upon its banks. At one period of an epidemic he thought it his duty to call the attention of the Privy Council to the circumstance, when the inhabitants were warned not to drink the water of the River Wandle. It was only by a series of Bills in Chancery that the residents succeeded in suppressing that nuisance; and it was observed that the Croydon authorities found the greatest difficulty in getting rid of the putrefying animal matter upon the land. He could give a recipe how to test imperfectly-purified water. It might be clear, and bright, and pleasant; but put it into a bottle upon the mantelpiece in a warm room, and in two or three days, notwithstanding the filtering process had removed suspended matter, it would begin to change, and give unmistakable evidence to the olfactory nerves of the presence of putrefying organic matter. Everything tended to show that animal matter in a state of decomposition was to be feared. In seasons of epidemic it was impossible to pass the excretæ of one town to another in rivers, without the danger of propagating disease; and for that reason water ought never to be taken from such a source. Now, if it was matter in a state of change which was injurious, there came the consideration whether the sewage was presented as a totally changed matter in river waters; in other words, whether the sewage assumed a totally different form. Suppose sewage was put upon the ground and absorbed by vegetables, such as cabbages, or was absorbed by weeds in rivers, it was no longer sewage; but, notwithstanding, there were several cases on record which showed that it was not perfectly safe to manure gardens by pumping sewage; under such circumstances, as the plants grew up they would quickly decompose after being cut for use, and would not be as wholesome for food as those manured with sweet and fresh fertilizing matter. But if the organic matter assumed another form, it was really a new substance and harmless. The question of changed matter was

brought forward every month by the Registrar General, and fallaciously estimated as pre-existing sewage, which had caused some persons to be misled as to the wholesomeness of perfectly unobjectionable waters. The matter must be utterly changed before it could be safely used, and that change could be effected on the strata of the earth, by long-continued contact with mould and air. There was reason to believe it was so with regard to chalk. Wherever the water percolated through chalk strata it was deprived of organic matter—perfectly deprived of that changing organic matter which he had referred to as being noxious, and which was converted into nitrites and nitrates. No doubt animal charcoal could do a good deal artificially; but while a great and perfect filter-bed existed in Nature, he held it was right and proper to get for a large town, especially for London, such an amount of water perfectly filtered by Nature as to extract all organic matter from the water, whether in the original or in the changing state. In that way alone could wholesome water, wanting no artificial filtration whatever, be supplied to the community.

Professor Ansted remarked that the question appeared to him to have rather an important geological aspect. It was not for him to touch upon the medical questions that had been discussed; but at the same time he might say that Nature herself was a great restorer, and that she was in the habit of bringing back into a healthy state all those things which, though sometimes called by ugly names, were in themselves only mischievous because it was not known how to deal with them properly. No doubt chalk was a material that purified the water that passed through it; but what rock was there that did not purify water? Every material, no matter what it might be, through which water flowed while beneath the surface of the earth must have some effect upon it; for water was an universal solvent, and could not pass through rocks without depositing some of its contents and taking up others. But he desired to point out what was the nature of those waters which came to the surface from springs. They were not in any case pure waters, in the chemical sense of the word. They were waters which always contained a considerable amount of inorganic matter, and even, in many cases, no small proportion even of organic matter. He spoke now of waters derived from deep natural springs, and rising to the surface highly mineralized. These were known as mineral waters: some of them were not only mineralized, but also contained organic matter to a large extent. The hot sulphurous waters of the Pyrenees were of this kind; they contained organic matter under the name of glairine, which existed in such a state as to involve, when it came to the surface, a peculiar kind of decomposition. Such waters were exceedingly favourable to the rapid growth of confervoid vegetation. They were also perfectly na-

tural, as far as any water could be so, and they had undergone no change by exposure, proceeding, in fact, from the depths of the earth, charged not only with nitrogen, but with matter distinctly organized. Now if these organic substances in a state liable to immediate decomposition were injurious, then these waters would be injurious. On the contrary, however, they were highly sanatory. He might say that all waters which percolated through the earth and came up again in springs were charged with mineral matter, including nitrogen; and if these matters were injurious, where, he would ask, was good water to be found? Water must be got for towns in some way, and there were certain well-known sources from which it could be obtained, and no others. First, there was spring water. In the case of large towns, spring water drawn from wells in the neighbourhood of churchyards might, no doubt, be loaded with decaying animal matter, which was very fatal; but spring water, even when not exposed to those evils, never could come to the surface pure. Spring water, therefore, though one of the most important, and, in some cases, most valuable sources, might seem open to serious objection, and could not be taken without inquiry for extensive use in towns. Lake water was another source, and was partly derived from rain, partly from springs. Nobody would say that lake water, whether from natural lakes or artificial reservoirs, was not liable to receive impurities both animal and vegetable. It might be good, but in its derivation it was no better than others. River water was another. Rivers themselves, like lakes, were derived from springs and rain. They received a large quantity of organic matter, which was necessarily decaying matter, and exceedingly unsuitable for consumption. But no one would assert that lakes were bad sources of supply. Neither could it be thought so for a moment of a river, even when it had received much decaying organic matter. On the contrary, after it had flowed for a certain distance it ceased to retain, in almost all cases, a sufficient quantity of such decaying matter as really to render its waters injurious to health. The whole question was one of observation and fact. He could indeed understand the possibility of theorising on this subject to a large extent, and was aware that those who looked upon matter thrown into rivers as the source of all mischief, seemed to entertain the notion that it must remain there, and never could be got rid of; but he could not understand how chemists and medical men could seriously state that decomposing organic matter entering streams in the ordinary manner was not really got rid of, and that too after a comparatively short time, by mere exposure to air, accompanied by considerable movement. In this respect rivers were better off than lakes, because in the still waters of the latter the organic matter was much longer being got rid of. River water was always in motion; it flowed over the surface, and was constantly disturbed;

fish lived in it, and what did they live upon? They lived upon smaller fish, and ultimately on animalcules. What were these animalcules? They were the contrivances which Nature had adopted to make use of all this otherwise injurious and even poisonous decaying matter. They greatly assisted in rendering running water rapidly pure; and exposure to the air and oxidation did the rest. He believed it to be a simple fact that a river, after passing a town, and receiving the whole of the sewage of that town, ceased to be in a dangerous state a few miles below. He believed this from his own experience, and was certain that river water might safely be used that had had a few miles' exposure to the air, provided, of course, the towns on its banks were not too large or too near together, or the quantity of impurity too great in proportion to the body of the water and the rate of its motion. It seemed to him, therefore, that rivers were the natural sources of supply to towns. They had always been so; and he apprehended, in spite of the feeling occasionally excited, because of the large quantity of impurities sometimes passing into them from towns, that there were, on the whole, no better means of supply than they afforded. He might repeat that all three sources of supply were available; for Nature had yielded water in various ways, and for various purposes, and men might avail themselves of all, according to circumstances. The rain that fell from the sky was not pure, especially in towns; for it contained ammonia, and various substances present in the air; but still soft rain water was very useful. Of the rain that fell upon the earth, one part ran upon the surface, another entered into the rocks. Both were equally useful. Which source should be used in a particular case was a matter which must be decided locally. There were cases in which one kind of water could not be used, owing to local influences. He quite understood the allegation of the existence of impurities in the water supplied to certain towns in particular cases. No doubt this had been so; but then came the larger question, what should be the source of supply to towns, if they could neither use the rain water nor the water from such wells as could be most conveniently sunk? In many cases it could not be considered advisable to use well water in large towns, because such wells were liable to injury; but that towns might not draw their supply from the streams which passed by them, and that the water so conveyed was not capable of being utilised by some simple process of filtration was, he believed, contrary to all experience. Speaking on the subject geologically, and with reference to the condition of the interior of the earth in these matters, he was safe in stating that most of those mineral substances which were regarded as impurities in water naturally belonged to water, and that water was never free from them in the natural state. Water was an almost universal solvent, and in passing through the earth

underwent great changes, parting with some substances, taking up others, and often coming back not in a simple but in a highly mineralized state; useful for certain purposes, but not always adapted for drinking, washing, or manufacturing. The ordinary state, however, of springs, as of lakes and rivers, was no doubt that in which they contained a comparatively small amount of mineral salts; and that ordinary state was the only one engineers had to deal with. The tendency, also, of river water was, by a process of gradual and natural purification, to yield good usable water, occasionally fouled, but almost always recovering itself; and he would say that, so far from any danger being incurred from river water, except under very exceptional circumstances, the idea of such danger might be put aside as contrary to experience, and contrary to the principles of natural science.

Mr. H. Shield exhibited the following Tables, showing the effects of sand and of vegetable charcoal upon water taken from the River Thames at Kingston by the Chelsea Water Works Company:—

Table I.

Results of Filtration through Charcoal in Lumps of the size of a Walnut. Water taken from the River Thames at Kingston. Experimental Filter No. 1. (Page 29.)

——	Original Water used.	After 67 Hours' Action.			After 91 Hours' Action.		
		Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.	Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.
Total residue . .	23·949	23·668	0·281	1·17	22·076	1·873	7·82
Mineral salts . .	22·519	..	..	..	21·618	0·901	4·00
Organic matter .	1·430	0·475	0·955	66·78	0·458	0·972	68·00
Chlorine . . .	1·054	..	..	..	0·973	0·081	7·685
Chloride of sodium	1·737	..	..	..	1·603	0·134	7·714
		After 115 Hours' Action.			After 139 Hours' Action.		
Total residue . .	23·949	23·012	0·937	3·91	23·411	0·538	2·242
Mineral salts . .	22·519	..	..	..	22·440	0·079	3·66
Organic matter .	1·430	0·620	0·810	56·67	0·971	0·459	32·10
Chlorine . . .	1·054	0·885	0·169	16·03	0·973	0·081	9·73
Chloride of sodium	1·737	1·457	0·280	16·10	1·603	0·134	9·8

TABLE II.

RESULTS of FILTRATION through SAND. Water taken from the River Thames at Kingston. Experimental Filter No. 2. (Page 30.)

	Original Water used.	After 23 Hours' Action.			After 120 Hours' Action.		
		Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.	Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.
Total residue . .	24·578	23·87	0·708	2·88	23·69	0·888	3·613
Mineral salts . .	23·687	22·858	0·829	3·50	23·04	0·647	2·73
Organic matter .	0·8906	1·012	..	..	0·648	0·2426	
Suspended matter	3·509	2·663	0·846	24·109			
Chlorine . . .	0·862	..	..	..	0·671	0·191	22·16
Chloride of sodium	1·420	..	..	..	1·105	0·315	22·11

		After 240 Hours' Action.			After 376 Hours' Action.		
Total residue . .	24·578	22·534	2·044	8·316	22·507	2·071	8·426
Mineral salts . .	23·687	21·517	2·170	9·161	21·698	1·989	8·397
Organic matter .	0·8906	0·917	..	..	0·809		
Suspended matter	3·509	1·88	1·629	46·423	1·584	1·925	54·85
Chlorine . . .	0·862	0·674	0·188	21·8			
Chloride of sodium	1·420	1·110	0·310	21·8			

TABLE III.

RESULTS of FILTRATION through CHARCOAL in Granules. Water taken from the River Thames at Kingston. Experimental Filter No. 3. (Page 30.)

	Original Water used.	After 72 Hours' Action.			After 120 Hours' Action.		
		Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.	Comparison.	Amount separated.	Per Centage Ratio of Quantity separated.
Total residue . .	24·578	22·13	2·448	9·906	21·644	2·934	11·93
Mineral matter .	23·687	21·375	2·312	9·76			
Organic matter .	0·8906	0·755	0·1356	15·22			
Suspended matter	3·509	..	..	..	3·06	0·449	12·79
Chlorine . . .	0·862						
Chloride of sodium	1·420						

		After 240 Hours' Action.			After 376 Hours' Action.		
Total residue . .	24·578	20·821	3·757	15·28	21·374	3·204	13·03
Mineral matter .	23·687	..	..	..	20·604	3·083	12·34
Organic matter .	0·8906	..	..	..	0·770	0·1206	13·54
Suspended matter	3·509	2·79	0·719	20·48			
Chlorine . . .	0·862						
Chloride of sodium	1·420						

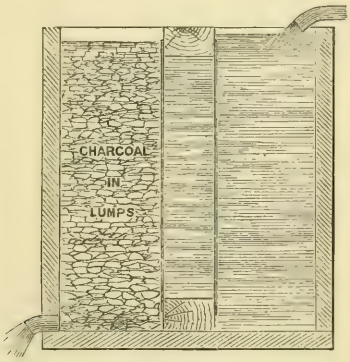
COMPARISON of TABLES I., II., and III.

Amounts of Total Residue originally present in each Case.	Number of Hours' Action of the Filter.	Amount separated in Grains in the Gallon by			Per Centage Ratio of Quantity separated by		
		Sand.	Charcoal in Granules.	Charcoal in Lumps.	Sand.	Charcoal in Granules.	Charcoal in Lumps.
Grains.	Hours.						
24·578	23	0·708	2·868	..	2·88	11·66	
23·949	67	..	..	0·281	..	..	1·17
23·949	91	..	..	1·873	..	..	7·82
23·949	115	..	..	0·937	..	..	3·91
24·578	120	0·888	2·934	..	3·613	11·93	
23·949	139	..	..	0·538	..	..	2·242
24·578	240	2·044	3·757	..	8·316	15·28	
24·578	376	2·071	3·204	..	8·426	13·03	

COMPARISON of TABLES II. and III.

Amount originally present.	Amount separated in Grains in the Gallon.		Amount separated by Per Centage of the Quantity present.	
	By Sand.	By Charcoal.	By Sand.	By Charcoal.
24·578 grains in the gallon .	2·074	3·757	8·426	15·28

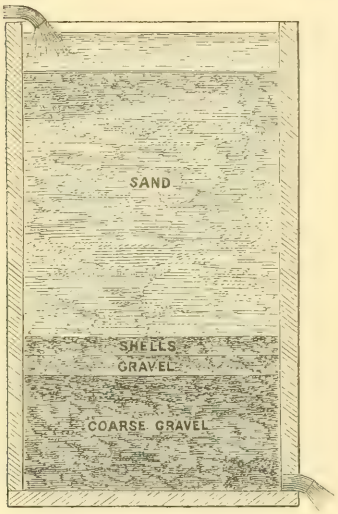
The rate of filtration in each of the three filters experimented on was half a gallon per minute; and, as the time each experiment lasted was given in the Tables, it would be easy to calculate the amount of water passed. In filter No. 1 the filtering surface exposed was about 4·38 square feet, the filtration being lateral and descending.



Experimental Filter No. 1.

The sand filter No. 2 had an area of 4 square feet, and consisted of the following materials :—

	Ft.	In.
Fine sand	1	9
Shells	0	$1\frac{1}{2}$
Gravel	0	$1\frac{1}{2}$
Coarse gravel	0	9
	2	9



Experimental Filter No. 2.

In No. 3 filter the fine sand was replaced by charcoal in granules of about the size of a pea; in other respects it was the same as filter No. 2.

It would be seen from the Tables that, after removing a considerable amount of impurity from the water, the charcoal steadily decreased in the efficiency of its operation. The experiments with the sand filter proved that, while sand removed much less of the impurities than charcoal, the effect went on increasing up to the end. The filters were about half the depth of the actual filter-beds of the Chelsea Water Company, so that the results were not so favourable as those effected in the ordinary operations of the Company, which appeared in the monthly report of the Registrar General. The small quantity of organic matter removed by sand in cases where the amount originally present was but small was worthy of attention. Other experiments, however, had been made with water of less purity, taken at Chelsea at different seasons, and the result of these showed that the case was altogether altered when the quan-

tity of organic impurity, originally present, was considerable. Thus 20·46 per cent. were removed from water containing 2·375 grains of organic matter to the gallon, and 66·66 per cent. when 4·05 grains were present. He was of opinion that the action of the sand was not of a chemical nature, but that the attraction of cohesure, or adhesion, exerted on the surface of the sand in contact with the impurities, constituted a physical force sufficient to overcome the weak chemical affinity in virtue of which salts were held in solution, and to cause the exposure to the action of the air, and consequent neutralization of much of the organic impurities. Possibly the portion of organic matter removed was that which was in a state of decomposition, and which alone was noxious to health. He was sorry the results of the magnetic carbide system of filtration had not been given by Mr. Spencer, because he could have shown that sewage matter could be filtered to half a grain of organic matter to the gallon; but he believed the magnetic filter could not be relied upon to remove traces of less than half a grain to the gallon. However, by the use of the magnetic filter sewage water, flowing into a river, could be made tolerably innocuous, even in cases where the sewage was present in such quantities that the operations of Nature could not effect this, and where no means could be devised for intercepting the sewage, and carrying it by a special channel to an outfall of its own. He thought this discussion could hardly fail to prove that the London Water Companies supplied river water of excellent quality, and not what had been in some instances imagined by the public; and a reference to the monthly reports of the Registrar General would fully confirm this view. The report for October, 1867, gave, as the average for the eight Metropolitan Water Companies' supply, ·210 lb. of organic carbon in 100,000 lbs. of water, against ·256 lb. of organic carbon in 100,000 lbs. for Loch Katrine water; and no question had ever been raised about the excellent quality of this last supply.

Mr. G. W. Hemans considered, that there were two questions to be determined. One was whether filtration could be made available to purify foul water; the other was, whether filtering was necessary, and whether the waters which came through the rivers were not already good enough, by the operations of Nature, for general use. With regard to the extraordinary results obtained by Professor Frankland, neither he nor anybody else had hitherto mentioned how often it would be necessary to renew the charcoal for filtering purposes: but on the assumption of the lower rate of speed, he calculated that a surface of 270 square yards of charcoal, 1 yard thick, would be required to filter the daily supply of water to London, estimating it at one hundred million gallons. That would amount to a weight of about 170 tons of charcoal. If he was right in saying that the cost of animal charcoal was £20 per ton, or £15 per ton, supposing it to be changed once a month, which he

thought might be a fair assumption, the cost, at £20 per ton, would be £50,000 a year, and at £15 per ton three-quarters of that amount. But if it turned out that the half minute of contact was wholly insufficient, and that ten minutes of contact were necessary, the expense of filtering with animal charcoal might amount to £400,000, or even £500,000 a year. He thought, in short, that more data were required on this point. Turning to the other subject, as to whether rivers were capable of giving pure water, he thought the public mind would hardly receive or tolerate the idea, that because Nature had provided them they should be used in their present state. In the report of the Rivers' Pollution Commissioners, a description was given of the foul state of the River Thames, of the Aire and Calder, and of the Rivers Lee and Clyde ; and as the valley of the Thames delivered the sewage of a million of human beings, condensed within a small space in large towns, it would lead to the very opposite inferences. He thought the more general belief would be, that it was better to procure pure water, of a quality such as no rivers in low populous valleys could furnish, and that if it could not be got in any other way, it must be obtained from mountain sources. The Commissioners on the Pollution of Rivers recommended that every town should be compelled to utilise its own sewage, by the process of irrigation on grass lands, which would produce profitable crops, and would to a great extent deodorise and improve the condition of the water. No doubt that was an excellent remedial measure, which would be largely adopted in this country ; still he doubted whether it would remove all the offensive matters in solution in the water, and render it fit for drinking. Besides, he did not think the remedy would be sufficient; but that, in communities like that of London, the ulterior result would be that it would be necessary to have recourse to the rain water from the mountains in its pure condition. It was a mistake to suppose that the rain water collected from mountainous districts was turbid. If there was no foul matter to make the water turbid, it would not be so. The water from the great slate formations of North Wales and Cumberland was not turbid; on the contrary, the rivers there were pure and fine.

Mr. Edwin Chadwick, C.B., begged to make one suggestion. There had been proposed and tried, during the last few years, various methods of water supply for towns. Besides the old methods of river supplies, might be mentioned supplies from the surface washings of cultivated or of uncultivated lands ; supplies from springs—gathering grounds from hills—contoured by ditches, led to storage reservoirs ;—there had been changes from river to spring-water supplies ; from hard-water supplies to soft-water supplies ; soft-water supplies from surface gathering grounds, and soft-water spring supplies, delivered direct, without the intervention of storage; and changes from river supplies to artificial springs,

or subsoil collections, by means of agricultural permeable tile drains. There had been the changes in the methods of delivery,—intermittent supplies to constant supplies, changes in the engineering methods, from delivery by stand pipes, in courts or alleys, to delivery within the houses of the poorest classes by constant supply, and connection with water-closets, sinks, and houses. There had also been changes from storage in uncovered reservoirs to storage in covered reservoirs. He submitted, that it would greatly conduce to the advancement of this branch of engineering science, as well as to sanitary science, if there could be a competent examination, by scientific men, free from professional interest or bias, who would compare premises with results, in money as well as in quantity and quality, of the supplies given. In respect to the changes from hard water to soft water, he apprehended that, upon such an examination, if those who had been used to soft-water supplies, such as that of Manchester, were questioned as to their experience of a hard-water supply, as in coming to live in London, for instance—as to the comparative agreeableness of the two in washing, as to the saving in tea, and other soluble matters, as well as in soap, there would be little difference of opinion on the subject, apart even from medical testimony as to the results in improved digestion. It would be found, too, that water of the first degree of purity at its source, frequently became highly impure in consumption from methods of delivery;—that water stored in stagnant open reservoirs had rapid growths of vegetation, then animalcules, then decomposition of animal and vegetable matter, which subsequent public or private filtration only partially removed; that water kept in stagnant butts or cisterns on the intermittent system of supply, near cesspools, or middensteads, or in close courts, absorbed great quantities of the mephitic air of the place;—that water pure at its source, even the purest soft water, delivered by stand pipes in close courts or alleys, and taken up by poor people into overcrowded and foul living and sleeping rooms, and kept standing there in such open vessels as they had, became in a short time offensive to the smell and nauseous to the taste, and fraught with injury to the bodily system;—so that, considering how much the quality of water was dependent on the quality and the quantity of its aëration, it might be said that it depended on the engineering methods of delivery, whether the man in the town was drinking with the water mountain air or sewer air. Hence it would be found that, by defective methods of delivery in cesspool-tainted towns, augmented supplies of pure water had so little effect on death rates. Hence, too, the need of comprising the minor or house deliveries with the main deliveries, under one common sanitary superintendence, and that a public and responsible one. Then again, the effects of some water on various sorts of metal in deli-

very ought to be more carefully examined; and lead piping got rid of, and the use of earthenware pipes, now spreading on the continent, considered. He would observe, that when horses were taken from soft-water districts, as from those of the Surrey sands, for example, where their coats were smooth and bright, on a change to a chalk-water or a hard-water district, their coats became rough and staring, and they were subject to intestinal disturbance. So important was soft water to them, that horse trainers carefully collected rain water from slate roofs, and kept it in deep covered tanks, for the horses to drink, and carried the soft water with them, for the use of the animal at the racecourse. And whatsoever cows did for themselves, having really seldom any choice, what careful cattle-feeders did for them, was to get the best water that could be obtained. As to the instances cited of the effect of tainted springs on cholera in epidemic conditions, life appeared to be depressed, and the power of withstanding noxious agencies reduced, and sometimes the power of these agencies was increased by decomposition. Certain it was that persons then suffered from matters which at other times they bore with impunity. It was so with water. Impurity in water was then most injurious and fatal. This was so distinctly proved to be so as to lead extensively to the popular belief, in cholera periods, that the wells and common drinking waters had been poisoned; and in those epidemic conditions impurities might be said to be poisonous. Chemistry, which had as yet failed to remove completely the matter of sewage held in solution, would, he believed, be found to fail also in the complete removal of other impurities. Well-water might be said to be filtered water, which in towns was certainly dangerous at such periods, and it would be found that the success of the common filters on a large scale was very far from what was needed; that was to say, the filtrations of large quantities of water through comparatively small amounts of solid matter. The most efficient filter for the removal of matter in chemical solution, as well as matter in mechanical suspension, had yet, however, to be noticed, namely, filtration through strata occupied by vegetation. This had been brought under his observation by seeing two outfalls from land of the same stratum. From the one outfall the water was the surface washing of cultivated land, from which storm water was running much of the colour and consistency of pea-soup, contributing to the river supply dung and animal matters carried away in suspension. From the other outfall from the same land, subsoil drained, the water was running as clear as crystal; the surface matter carried away in the former being detained in the soil as in a great filter. Common filters of sandy or other soil without vegetation were little more than sieves, removing from water little that was held in solution; whereas in passing through a stratum occu-

pied by vegetation, a great deal, if not the whole of the matter held in solution was removed, as appeared from chemical analysis by Professor Way. Thus water collected from such grounds as the Bagshot sands would be more free from organic matter, if derived from properly adjusted permeable subsoil drains, than if gathered from the surface. The land, subsoil-drained, formed of itself a vast filter through vegetation. The filter was the more perfect if the drains were properly adjusted. They might be made too shallow. If they were too deep, they were apt to derive mineral matter from the ground. Sandy sterile land was excellently fitted for the filtration and collection of water. Some of these land-filters appeared to detain matter brought down by rain, and to yield water absolutely purer than rain water carefully caught. Of course on occupied land even the extensive and superior filter and gathering ground thus constituted might be overborne by heavy overdosing with manure, especially by putrid sewage derived from drains and sewers of deposit, and by irrigation by submersion, where 2 or 3 inches of water were put on at a time, instead of by fresh sewage from self-cleansing tubular drains and sewers, applied in such moderate and repeated doses as to allow full and fair action to the peculiar powers of vegetation in taking up animal and vegetable matter. Where such means were unavailable, considering the cost of private filtrations, as well as of large or public filtration, and the cost of works to take out organic matters from water supplies, and their common imperfection (of which there was extensive experience in London during storm periods), he believed it would be the most economical course to prevent such matters getting into the water; and where water was derived from gathering grounds of granite or slate, or other primitive formations, as proposed, that it would be worth while to strip the rock of the commonly thin covering of peat, or other vegetable matter, and make the surface absolutely bare and clean, and lead the water away in covered channels to covered reservoirs, and from thence direct to the houses; and considering the value of perfect purity in drinking waters, to prepare surfaces expressly to catch rain water. These observations he offered as indications of the points on which close competent examinations should be made on the spots, of what had been done, or attempted to be done, to arrive at impartial and safe conclusions, for the public satisfaction, as well as for the advancement of engineering and sanitary science.

Mr. E. A. Cowper stated that animal charcoal could be reburnt for 20*s.* per ton, and it might be reburnt twenty, or even fifty times over, and still be perfectly good for refining sugar.

Dr. Letheby communicated, through the Secretary, the results of some additional experiments made by him on the purifying and oxidizing power of animal charcoal.

Thinking that an examination of charcoal, which had been in use for some time as a filtering agent, might throw some light on its real function as a purifier of water, he obtained from the London and General Water Purifying Company samples of charcoal from a No. 4 filter, which had been in continual use at a house in St. George's Square, Pimlico, from the month of November, 1865, to the time when the samples were taken out of it for his inquiries —that was for a period of exactly 2 years; and he was informed that during the whole of that time it had been daily filtering about four hundred gallons of the Chelsea Company's water; so that about two hundred and ninety-two thousand gallons of water had passed through it. Now it appeared to be a matter of great importance to ascertain whether the filter still had the power of purifying water, and whether it contained any notable quantity of organic impurity locked up in the pores of the charcoal. He therefore first examined the capabilities of the charcoal as a purifying agent; and he found that when water supplied by the East London Water Company was filtered through the charcoal at such a rate that there was about three minutes' contact, the water was not merely deprived of its colour, as shown by an examination of it in a two-foot tube, but it was also deprived, in the usual way, of organic matter. This he ascertained by the permanganate test, and by distillation with caustic potash. It was evident, therefore, that the charcoal still acted as a purifying agent. He next examined the charcoal for organic impurity; for if it had been removing organic matter from water at the rate of only a tenth of a grain per gallon, it ought to have contained within its pores a very considerable quantity—not less than 4 lbs. of organic matter. Three examples of the charcoal were therefore submitted to distillation with a large excess of caustic potash, and the amount of ammonia obtained from 4 ounces of each of the samples was:—

Charcoal from Top of the Filter	0·321	grain ammonia.
Ditto Middle of ditto	0·162	„ „
Ditto Bottom of ditto	0·240	„ „

Thus showing that the quantity of nitrogenous organic matter in the charcoal was very inconsiderable. What, then, had become of all the organic matter which the charcoal had for 2 years removed from the water? It had evidently not accumulated in the filter, and there was no proof of its having been first absorbed and then set free. To determine this question, he put a known quantity of decaying organic matter into East London water, and filtered it through the old charcoal. In three minutes the organic matter had almost disappeared, and the filtered water contained a notable quantity of nitrite, which must have been produced by the oxidation of the nitrogenous matter which he had put into the water. This effect was tested still further by adding a drop of ammonia to a large volume of water,

and then testing for ammonia, and for nitrite after filtration. As in the last case, the ammonia had nearly disappeared, and nitrite had taken its place. These results showed beyond question that the purifying power of charcoal was not merely dependent on the fixation or physical absorption of organic matter, but also on its power of oxidation; and it appeared to him that two conditions were necessary for the destruction of organic matter in water—first, its being in a state of change or decay, and secondly, the existence of free oxygen in the water. When these conditions were present, he found that even sand would act as a purifying agent, although its power was far less active than that of animal charcoal.

He was not desirous of reopening the discussion of the effects of organic matter on health; but he could not avoid saying that the different and often contradictory opinions respecting this subject were evidently referable to two causes. One was, that all kinds and conditions of organic matter in water were often regarded as equally hurtful; the other, that the subject was contemplated from very different points of view, according to the habits of the observer. This indistinct and indefinite notion of the nature of organic matter did not permit the common observer to perceive that organic matter could only be hurtful when it was in certain states of change or decay, or when it was endowed with specific powers of morbific action, as in the case of the germs of disease, and perhaps also where, as it would seem, the excrements were hurtful to the animals or vegetables excreting them, but not to others of different species. And in respect of the second cause of error and uncertainty, it was evident that a truly pathological phenomenon could not be understood or clearly perceived by those whose avocations were of a strictly physical or chemical nature. In point of fact, the most mischievous dogmatisms of the present day, as regarded this important subject, were those which were propounded by men who were either ignorant of the laws of physiology and pathology, or who had little else for the basis of an opinion than the uncertain data of so-called statistics.

Mr. Vignoles had been informed by Mr. Lindley, Engineer to the Berlin Waterworks Company, that the water supplied to the inhabitants of that city was derived from the River Spree. Previous to being received into the tank or reservoir for distribution, the water was passed through filters, and was freed from all impurities; but after remaining in the tank for a day or two, the whole surface of the water got covered with confervæ and vegetation of various kinds: the water also lost its transparency, and became so turbid as to resemble the slush of the London streets. This naturally created great anxiety, and the managers of the works thought it necessary to stop the distribution once a week, in order to clean out the tanks. Upon the recommendation of Mr. Lindley, the

tanks for the reception of the filtered water were covered over, and immediately all the above symptoms disappeared, the water remaining in its original pure state. No doubt the covering of the tanks had prevented the contamination of the water; indeed it had long been understood that all tanks for the distribution of water ought to be covered over; but so strong a case as this he had never heard of before.

Mr. J. F. Bateman observed, that the last-mentioned fact accorded with the experience of those who had had anything to do with very pure water. In shallow reservoirs, a confervoid growth, like that spoken of, extensively prevailed, and on its decay, animalcular life sprang into existence, and the animalcules passed into the pipes. His attention was first prominently called to this about twenty years ago, in the case of the Warrington Waterworks, where the water was collected from gentle slopes of cultivated land of the New Red Sandstone formation into a reservoir, after which it was rendered perfectly pellucid by being filtered through sand, and was then passed into a tank not more than about 6 feet deep. Although that water was filtered as well as it could be, it very soon became filled with animalcules, for the separation of which he introduced a copper wire-gauze strainer of eighty strands to the inch; but it was so difficult to cleanse it from the animalcules, that he ultimately resorted to the covering over of the reservoir. This was effected, without emptying the reservoir, by erecting vertical pillars supporting cross beams, on which large flags were placed. As the work progressed, the confervæ beneath the covered parts gradually fell to the bottom; by the time it was finished they had entirely disappeared; and the water had been delivered in a pure state ever since. He considered it necessary that reservoirs should not be less than from 15 feet to 20 feet deep, if they were to remain uncovered, as experience showed that reservoirs of that depth did not generate confervæ. The service reservoirs of the Manchester Waterworks, which were lined with bricks throughout, that they might be cleaned from time to time, were 18 feet deep at one end and 20 feet deep at the other, and, as they were kept constantly filled to within a foot or two, there was never a particle of vegetation on them. They had not been cleaned out for the last sixteen years or seventeen years, nor did they require it, the water was so pure. At Wolverhampton the water was collected from the same geological formation as that at Warrington; the service reservoir at Tettenhall was 15 feet deep, and there was no vegetation in it; but he considered a less depth of water than 15 feet would be liable to generate confervæ in the manner spoken of, and in all such cases the reservoirs must necessarily be covered over.

The animal charcoal filtration, or rather the passing of water

through animal charcoal, seemed, in the results stated, to be most extraordinary to engineers who were in the habit of treating these things mechanically; and he could only say that if these results were true—and they were given by men on whose accuracy reliance could be placed—the process of purifying water might be made simpler, easier, and more convenient than had hitherto been the case. The purification of foul water would be effected, it appeared, if it were passed through a mass of charcoal, and the water, if discoloured, would be rendered clear, and be deprived of organic matter. He should be happy to avail himself of any favourable experience which could be gathered from the use of animal charcoal, and he felt much indebted to the chemists who had discussed the question. For his own part, although in many cases he had adopted filtration, yet in the large waterworks he had more recently constructed, he did not provide filter-beds, nor did he find it necessary to do so. Where water was taken from rivers, sometimes turbid, and always containing more or less foreign matters, and where it was taken from canals or reservoirs, supplied by water flowing from gentle slopes of cultivated land, it was necessary to filter it; and it was also occasionally necessary to filter water taken from shallow lakes. In the case of water taken from the shallow lake of Loch Rutton, for the supply of Dumfries; or in that of Rathmines, near Dublin, where the water was taken from the Grand Canal—a canal notoriously charged with foreign matter, the water was filtered; but at Manchester, Glasgow, Halifax, Blackburn, and many other places, there was no filtration. At Blackburn, filters were constructed in the first instance, but after a time the use of them was abandoned, because it was found that, by the system of decanting and drawing from the top of each reservoir, the water was supplied as pure as if it had passed through the sand filter. The water at Blackburn had been supplied in that way for the last twenty years. In the case of Manchester, the water was, to a considerable extent, separated; for the spring water, as it issued from the bowels of the earth, was conveyed in a separate watercourse, and was either taken direct into Manchester for present use, or stored till the springs fell below that point which was required for the supply, when the water previously stored was drawn upon. The fact had been demonstrated that water of a brownish colour when stored became bleached in the reservoir by exposure to the atmosphere. In the Belmont reservoir of the Boston Waterworks, which was wholly supplied from a district covered by peat, the water came in as brown as porter, but after about 3 weeks' exposure it became comparatively clear, and only slightly tinted. In like manner the value of exposure was shown in the instance of Loch Katrine, the whole drainage ground of which consisted of land covered by a coating

of peat and black earth. The principal streams flowing into that lake, viz., the River Gyle and the Strowan Burn, were at this season of the year as brown as mahogany; and yet the water collected was about the purest that could be seen. At any season, except perhaps in a wet autumn, a sixpence or a piece of white pottery could be seen at a depth of 10 feet, with only a pale straw colour imparted to it. He had recently been there when the depth of the water in the basin at the entrance of the tunnel was from 5 feet to 6 feet, and notwithstanding a considerable amount of rain had fallen, the white pebbles at the bottom showed of a pale straw colour only; but seen in a glass, the water was brilliantly bright. From this it was evident that there were many ways by which water might be purified. He had no doubt many of those present had seen the River Rhone as it flowed into the Lake of Geneva, and the water of that lake as it flowed out. They would also have noticed the condition of the water at the junction of the Rivers Rhone and Arve, about 2 miles below Geneva. The water as it entered into the Lake was largely charged with matters from the abrasion of the ground by the grinding action of the glaciers above, and for some distance after it entered the Lake the discoloration was very perceptible; but the water flowing out at the other end of the Lake was as brilliant, pellucid, and pure a stream as could be imagined, and that water was supplied to the inhabitants of Geneva. Then again, in the Manchester Waterworks there was no filtration; but in all such cases the water, after being decanted off and stored in large reservoirs, was received into service reservoirs 18 feet in depth, and was then strained through a large area of copper-wire gauze. He began with eighty strands to the inch, but that was found to be too fine, and the strainer now used was of sixty strands to the inch, that mesh being sufficient to separate the extraneous matter, and prevent its passage into the pipes.

The mechanical filtration of water, generally adopted by engineers, was by downward filtration through sand. He first studied filtration many years ago at the large print works and bleach works in Lancashire, where one or two million gallons of water were frequently filtered daily through sand for the supply of the works; and having watched the operation, he came to the determination to adopt the principle which was there successfully carried out. It consisted in having a shallow depth of water upon the surface of the sand, and slow filtration. In that respect the system differed from that which obtained in London, where there were 5 feet or 6 feet of water over the sand bed, whereas he never allowed more than 1 foot of water to rest upon the surface of the filter. The total thickness of the strata of the filtering bed was 4 feet. The upper 2 feet consisted of siliceous or quartzose sand, insoluble in water, with the particles as fine as bay-salt. If

not obtained clean it required to be very carefully washed. Below this was a bed of 6 inches of coarse sand or fine gravel, about the size of peas or small beans, the interstices of which were so close that the water in its passage could not carry down any of the sand from above. The next stratum consisted of 6 inches of coarser gravel of the size of Barcelona nuts and walnuts, which supported the upper strata; and at the bottom of all was a rubble foundation of stones of the size of potatoes and turnips; so that the whole system consisted in making the successive layers below the uppermost one so fine only that the material of the several strata should not be displaced. He saw no occasion whatever for the use of oyster shells, which were introduced into the London filters, the great object being to support the upper bed of sand by a proper gradation of the material downwards. He estimated that such a filter in good working condition would pass water at the rate of 6 inches vertically per hour, or seventy-five gallons per square foot of surface in twenty-four hours. This plan of filter was easily cleaned. When a less quantity of water than usual was filtered, the upper surface of the sand bed, which alone caught the extraneous matter, required to be scraped off, and a fresh surface of sand exposed, after which the filter did duty again.

Something had been said with regard to soft water and hard water; but as that did not form part of the subject of the Paper, he would not refer to the question; but he had endeavoured to show that there were several ways of purification which were effectual: these were—decanting in the manner carried out in several waterworks; by separation and separate storage; by the collection of water in large volumes; by deposition and exposure, and by taking the water from the lower end of a lake; and also by mechanical filtration.

Mr. J. A. Longridge thought it was not Professor Frankland's intention to state that water for large cities like London could be taken from the River Thames, or any other impure source, and that after being passed rapidly through a bed of charcoal 3 feet thick it would be perfectly pure. He thought he drew a distinction between the simple mechanical operation of removing matters in suspension and the removal of the more objectionable organic matter in solution; and that it was to the latter operation that he had directed attention. No doubt the mechanical operation was performed best by a large surface and small head of water and a slow process of filtration; and the way in which this was done had been well described in the course of the discussion. But the question arose whether it was necessary to remove the organic matter in solution from the water, and if so, what means should be taken to remove it. He was inclined to adopt the medical testimony on that point, notwithstanding an assertion that it had never been proved

that organic matter in suspension was deleterious. Perhaps the state in which it sometimes existed might not be injurious, but when organic matter became putrescent, it was unquestionably noxious; and engineers were bound to take every possible means of removing it. He did not believe that the ordinary attraction of aggregation would remove matter in solution from water; therefore if the organic matter existed in solution it must be got rid of by chemical action; and he saw no reason why this should not be instantaneous, as it would be accomplished by the simple contact of the particles of water with the chemical agent. Carbon had the power of absorbing gases, and it would absorb large quantities of atmospheric air; and if water from which all mechanical matter had been removed was passed through it, and each particle of water was brought into contact with the carbon, he conceived that the organic matter in solution would be at once oxidized and rendered harmless. It would not remain in the carbon, but would pass off in an innocuous form. The velocity of filtration in Dr. Frankland's experiments was not more than 6 inches per second, and he saw no reason to doubt their accuracy.

Mr. Webster, Q.C., remarked that fair discussion was what every man of science wished for. It had been observed that the great chemistry of Nature was developed in the supply of water; but as no reference had been made to a case which he happened to know was a great success, he trusted he might be allowed to mention it. He had seen the water of the River Severn, brown as coffee, passed through four or five of Mr. Hawksley's filters, and delivered in Worcester as pure as water could be. He called the attention of the Institution to that one fact, that any of the members going to the River Severn might examine how the water at Worcester, properly abused as it had been, when dealt with in the way described and by natural filtration, was brought back to such a state that even chemists themselves could hardly find a homœopathic dose of noxious matter in it. Chemists had given ultimate tests, and it was gratifying to find that by means of filters even the marsh water of the fens of Lincolnshire could be rendered wholesome. It was known that water might be defective from not being deprived of all colour, and yet it might be innocuous to health. But some persons not only desired to have pure water, but also wished it to be colourless. By the use of the carbide filter, after the filtering that had been described, water could be produced in a state fit for the consumption of large towns. That water of a deleterious nature would be found in some places was generally acknowledged; but as it came from the mountains and the bowels of the earth, or from this filter, it would be found in a condition to which no possible exception could be made. It was gratifying to find members of the medical profession and

chemists watching everything connected with this matter so closely; and he was convinced the discussion would have a good effect in reassuring the public mind on the question of water supply of large towns, coupled with the discharge of sewage matter into the rivers. The public might be reminded that there were going on in Nature chemical changes of such a character that pure water might be obtained either by the natural filter of the rocks and strata of earth through which it passed, or by the artificial filtration which science had introduced. By this chemistry of Nature, owing to the slow filtration that went on through these different beds, together with the presence of a large amount of oxygen, these detrimental matters were burnt out by the oxygen of the atmosphere by a slow yet sure process, by which an entire removal was effected of injurious matters in solution as well as those in suspension.

Mr. Lewis Oldrick regretted that neither chemists nor engineers had, up to the present moment, discovered how to determine whether the organic matter found by analysis in water was decomposed, and consequently deleterious to health, or not. A protest had been raised against the general belief that organic matter in water was dangerous; but he feared this would be calculated to mislead, and to be misunderstood, if not qualified. No doubt milk and live oysters, consisting chiefly of organic matter, were partaken of without harm, but the organic matter was not decomposed; if it were, it would be dangerous. Again, what could be more deceptive than a glass of clear water? As a proof of the correctness of this assertion, he would mention the Aldgate pump in the City, the water of which was much sought after for drinking purposes, because it was bright, sparkling, and cool, and of an agreeable taste. But the coolness and brightness were both derived from decaying organic matter, by which the water was impregnated while percolating through the adjoining graveyards; and according to Dr. Letheby's analyses, this very water contained 127 grains of impurities in the gallon, and out of these from 5 grains to 6 grains were decomposed organic matter. He would also mention the pump in Broad Street, Westminster, as an example of the dangerous condition of water apparently good but unfiltered. During the cholera epidemic a lady, becoming alarmed, removed from the neighbourhood of Westminster to Hampstead; but unfortunately, being fond of the pump-water she had been in the habit of drinking, she sent for water from the celebrated pump in Broad Street, and she was the only person in Hampstead who died of cholera. Out of seventy-three persons who died during the first days of this epidemic, it was proved that sixty-one had been drinking the water of the pump; and it was also remarked that in the same street, which received its water-supply from two different sources, on one side the

people died in large numbers, and on the other side very few died. These facts proved that it was of importance to use efficient means to remove organic matter from water before using it for drinking purposes.

It was equally a mistake to suppose that the air could not pollute water. During the last cholera epidemic there were three cisterns at the London Hospital. The cistern at each of the wings supplied good water; but the water from that in the centre of the building was contaminated with organic matter. At first there was no apparent reason why the water, which was supplied from the same pipe, was so different; but it was found that the centre cistern was placed in the ventilating shaft in such a manner that the emanations from the cholera patients passed it, and the impurities were absorbed by the water. However, on placing an animal charcoal cistern filter, of Mr. Danchell's construction, in each of the tanks, agreeable and wholesome water was at once obtained. House cisterns placed above water-closets got impregnated with the foul air; yet, from some unaccountable whim, builders, as a rule, placed the water-cisterns in this position. At the present time the water was filtered at great expense to the Water Companies, then brought by miles of mains and delivered into the cisterns, which were often placed where it was impossible to clean them, or, if this was practicable, the servants generally neglected them, and they got into a dirty condition; and that water, which had cost thousands of pounds to filter, by the time it was drank was in a foul and filthy state, not fit for a human being. Would it not be better to obtain the water effectually filtered at the moment it was drawn off for use, thus escaping the possibility of its acquiring fresh impurities after having been once filtered? This could be done by applying cistern filters, such as the one exhibited by Mr. Danchell.

With regard to the speed of filtration, about which a question had been raised, he believed Dr. Frankland intended merely to show the extreme of speed at which water could be passed through the filter; just as in the case of testing the speed of marine engines; they were worked at their highest power over the measured mile, and showed an amount of efficiency which was not attained afterwards. In practice it was easy to regulate the quantity of water passed through the filter, according to the requirements of the case.

The Author of the Paper had stated that the filter, after a certain time, was not to be depended on; but he had forgotten to give any hints as to when the filter ceased to act correctly. He would therefore draw the attention of the Meeting to a water-testing apparatus, which, though little known, was both simple and ingenious. By means of this apparatus, every householder could, without chemical knowledge, test the water which his filter pro-

duced; and as all the tests were made dependent upon the appearance presented by the water after the addition of one or other of the test fluids, it was not only useful to the householder, but also to the engineer, who did not possess the knowledge of a chemist; as it would be more convenient to use it when there was a question about the quality of water, than to go to the expense of employing an analytical chemist. The tests were :—

1. For ammonia. 2. For decomposed organic matter. 3. Negative test for lead; *i. e.*, whether it was possible for the water to contain lead. 4. Positive test for lead; *i. e.*, whether the water did contain lead. 5. For carbonate of lime or carbonic acid. 6. For sulphate of lime or sulphuric acid. 7. For iron. 8. For chlorine or chlorides. 9. For phosphates. 10. Auxiliary test to No. 8; more refined. By these tests, where doubt existed as to the efficacy of the filter, impurities in the water could readily be detected.

There was another apparatus for softening hard water for manufacturing purposes which had not yet been mentioned: it was invented by Mr. Danchell, and was simply a practical application of Dr. Clark's process of reducing the hardness of water by the addition of lime.

Mr. Heisch was not prepared to take part in the discussion, not having been present at its commencement; but there were one or two points on which he would say a few words. One was with respect to the filter which had been last referred to. Filters of that description were fitted to all the cisterns at the Middlesex Hospital, under the direction of "The London and General Water Purifying Company," whose inspector attended, and fixed the sizes suitable in each case. The filters were allowed to remain for a certain time, but in consequence of complaints of a want of water, the Committee determined on having them removed. Notwithstanding this deficiency of supply, the water that did come through did not appear to be improved. He analysed it several times, and in no case did it differ from the water that was taken direct from the cistern. He did not mean to assert that animal charcoal was not efficacious: but in this particular instance, the water, he thought, passed too quickly, as far as the removal of organic matter was concerned; while the filter was too slow in its operation to supply a large establishment like a hospital. Nothing could be done in a place of that sort without an apparatus which allowed the filtering to go on very slowly, and provided for the storage of the filtered water, instead of the water being drawn through the charcoal as it was wanted.

With respect to the permanganate test, that was a point which had been examined by chemists for many years; and he was very happy to find that, within the last two years, Dr. Frankland had

come to the same opinion that he had long since formed, that it was not a thing to be depended upon. Nearly twenty years ago he made experiments, in conjunction with his colleague, Mr. T. Taylor, with different kinds of organic matter. To put the thing as strongly as he could, he placed a grain of urea—the nitrogenous principle, so to speak, of urine—into one portion of water, and a grain of sugar into another, the quantity of water being exactly the same in both cases; and the sugar decolourized forty times the quantity of permanganate of potash that the urea did. Therefore he did not think it was a test that ought to be depended upon. It was a useful one in some respects, particularly if notice were taken of the time required for decolourizing, after having ascertained that there were no inorganic matters in the water which produced decolouration; but it was a gratuitous assumption to assert that there was no deleterious matter in the water when little decolouration was produced by the permanganate of potash.

Mr. C. E. Austin communicated, through the Secretary, an account of a filter, or strainer, erected some years ago for the Russian Government at St. Petersburg, by Mr. Bryan Donkin, for the purpose of straining the water of the River Neva, and rendering it sufficiently pure to be used in the manufacture of bank paper. The water of the River Neva was what was generally termed soft water; but it held in solution a large quantity of matter extracted from decomposing vegetable substances, which would by chemists be probably called organic. The strainer was made up of several troughs, placed one above the other in the manner of steps. Each trough, forming a step, was divided longitudinally by a partition, which did not reach the bottom, into two compartments, the inner one of which was covered with wire gauze, and received the water as it fell from the step above, and the outer one of which contained the horizontal-lipped orifices through which the water escaped as it flowed to the step below. The total area of wire gauze was about 420 square feet, and its mesh admitted fifty strands to the inch. The conduit from the pumps which supplied the water communicated with the upper step, and the lower was superposed to one of four sand-and-gravel filter tanks, each containing an area of 588 square feet of filtering surface. The water ran down the conduit from the pumps, and filling the highest or first step, flowed over its lip and fell into the second step through the gauze covering of the inner compartment. From the second step it overflowed and fell through the gauze covering of the third, and, filling that step, it descended in like manner through the gauze and troughs of the fourth and fifth steps, whence it escaped into the filter tanks, and, passing downwards through the filtering materials, arrived at the deep wells in which it was stored for use. One hundred thousand cubic feet of water were filtered in ten hours.

The fall of the water from step to step was 2 feet, and it should attain in that fall an average velocity of about 3 feet per second. It flowed over the horizontal lip of each step in a sheet about $\frac{3}{4}$ of an inch in thickness, which was reduced in falling, and again expanded by contact with the gauze to about the same dimension. The utilized length of each step was 17 feet 6 inches; and thus, of the whole area of gauze, amounting to 420 square feet, the water occupied in its passage only 4·4 square feet, falling four times through a gauze area of 1·1 square foot. The water entered the first step in a perfectly pellucid state, but before it had passed through two sheets of gauze it became turbid, and deposited a black scum on the wires, which required constant cleaning, so great was the quantity of deposit. In the first tank the water was partially covered with a black scum of froth, sometimes more than an inch in thickness, and a thin scum, having a metallic lustre, appeared on the surface of the water in the second reservoir. He had not analysed this deposit, but to all appearance it was similar to that thrown to the surface of foul water in general during its natural process of purification, which was in this instance accelerated, partly by continued exposure to the atmosphere, and partly by the impediment to the grosser particles caused by the repeated passage through the gauze. Now here, again, a perceptible chemical effect was produced by a mechanical action, undoubtedly very similar to that of the passage of water through sand: the sand, however, retained in its mass the whole of the separated matter, whilst the gauze left it to appear on the water in the form of scum.

All that had been said during the discussion on the effect of mechanical filtration tended to show that substances in a state of what was called solution were really in no other elementary form than that of a minute division of particles in suspension. What was known about natural filtration would lead to such a conclusion; for constantly recurring instances evinced that, where there was no reason to believe any chemical reagents could exist, foul water, subjected to the mechanical action of continued attrition, in its passage through natural beds of rock and sand, was thereby rendered completely pure. In these cases, when no action could be attributed to chemical affinity, there was every right to infer that the purification of the fluid was produced by the gradual relative retardment and collocation of particles of matter of various gravities and forms; the motion, by the attrition of the filter, being abstracted soonest from those which were heaviest and roughest, whilst the most subtile retained their motion longer, leaving the others behind. There was no reason to believe that the purifying effects of irrigation on sewage arose from any other cause than this mechanical action; but its advantage over other processes consisted in the use of a more extended surface for filtration and exposure to

the atmosphere, which undoubtedly produced a relatively greater effect. The constant growth of the crop absorbed the matter deposited, and thus its intrinsic action rendered the surface fit for the reception of successive deposits.

Mr. Byrne observed, that there were various opinions held as to the best method of estimating organic matter in water. Considering the unsettled state of this question, it could not be wondered at that Dr. Letheby, in his water analyses, should still adhere to the incineration process, controlled by the permanganate test; but it seemed strange that, on this particular occasion, he should have attempted to decry a system which, it was well known, he had himself invariably adopted. Dr. Frankland, too, had employed the same system in arriving at many of the results which he had quoted in opposition to those given in the Tables. Of course the loss of weight by ignition was due, not only to organic, but to other volatile matter —a fact fully recognized in the Paper; but, as the water dealt with in these experiments contained neither nitrites nor ammoniacal salts, in any appreciable quantity, the volatile matter had been spoken of as consisting of organic matter and nitrates. According to the researches of some chemists, salts containing one or other of the alkalies for a base were either not absorbed at all, or very slightly so by animal charcoal.[1] In fact, charcoal had been employed to remove organic matter from solutions of nitrate of potash, for which purpose it would not have been suitable if the nitrate of potash itself were also absorbed. This tended to prove that, of the amount lost by ignition, the larger portion was probably due to organic matter, and not to nitrates. It must be admitted that the water used in these experiments, like any other natural water, contained organic matter; and it would be seen, by looking at the 5th column of Table 2, that the permanganate of potash was deoxidized by something in the water, both before and after filtration. There was no protosalt of iron present; and, as nitrates and chlorides could not effect this, the deoxidation must have been due, almost entirely, if not completely so, to the organic matter itself. It was, therefore, a mistake to suppose that the question of removing organic matter, by means of animal charcoal, was left untouched by these experiments. There was no doubt that animal charcoal absorbed organic matter; but the chief question now was as to the extent that it would do so, as to whether any of the organic matter so absorbed would be given up again, and whether it underwent oxidation, or not, by means of the charcoal. A liquid would not dissolve an unlimited quantity of a solid, were the latter ever so soluble in that liquid. Substances also combined chemically in definite proportions by

[1] *Vide* Translation by Ronalds and Richardson of Knapp's "Chemical Technology," vol. iii., pp. 442 and 443.

weight. It would, therefore, be indeed surprising, if a given quantity of charcoal were not limited as to the amount it was able to absorb of any particular substance; and, as it acted merely by surface attraction, if the quantity of the substance absorbed were not exceedingly small as compared with that of the charcoal itself. The process of refining brown sugar afforded a striking example of this fact: to remove the minute quantities of colouring matter existing in the sugar, a large quantity of charcoal was required, and, after all, the removal was only partial, as the second and third crops of crystals obtained from the sugar solution purified by charcoal, and which were technically called 'pieces' and 'bastards,' were always brown. The water used in his experiments contained a larger amount of salts in solution than was generally the case in water supplied to towns, but the waters of some metropolitan wells were still more highly charged with salts. Moreover, although he believed that, had the water dealt with contained a small, instead of a large amount of salts in solution, the charcoal would have been effective for a longer period, both in the removal of organic matter, and in reducing the hardness of the water; yet the performance of Dr. Frankland's filter did appear incomprehensible. Any reduction in the hardness of the water must have been the result of a corresponding removal of certain salts; so that, according to Dr. Frankland's statement, in a much shorter time than that during which the filter was said to have acted, the charcoal would have absorbed an amount of salts almost equal to itself in weight, and its pores would have been choked, long before which all action of a removing nature must have completely ceased. An account had been given by Mr. Shield of some experiments, on the action of sand and charcoal as filtering materials, made under the direction of Mr. Simpson (Past-President Inst. C.E.), with the co-operation of the Assistant Chemist of the London Government School of Applied Science. According to these, sand, as a remover of organic matter, though inferior to charcoal at first, was found to be, comparatively speaking, permanent in its effects. The experiments recorded in Table No. I. (page 27), which was the most satisfactory as regarded charcoal, would be sufficient for consideration. The original water contained 1·430 grain of organic matter in the gallon. After sixty-seven hours', ninety-one hours', one hundred and fifteen hours', and one hundred and thirty-nine hours' action, beyond which the experiments had not been carried, the quantities removed were found to be 0·955 grain, 0·972 grain, 0·620 grain, and 0·459 grain respectively. The charcoal had been tested under favourable circumstances, for the water dealt with contained but a small amount of organic matter, and on this the charcoal had been allowed to exert almost all its removing power, inasmuch as there was little or no absorption of inorganic constituents to interfere with its action. Nevertheless,

the amount of organic matter removed from being 68 per cent. on the original quantity, after ninety-one hours' filtration, was reduced to about 32 per cent. after forty-eight hours' further filtration. This result was not different from what he had been led to expect from his own investigations; but it was far from according with the views of those who proposed to effect the purification of a metropolitan water supply by adopting a rate of filtration about five hundred times faster[1] than that employed in the experiments just described, and by using the charcoal for six months without renewal or burning.

With regard to the time of contact necessary between charcoal and water in the process of filtration, in order that one should exert its full effect on the other, there was a curious difference of opinion between Dr. Letheby and Dr. Frankland; for, whereas the former insisted on the necessity of a slow rate, the latter considered that the object sought for would be equally well attained by a rapid rate of filtration. In the experiments recorded in the Paper, the filtration had been carried on at a much slower rate than what Dr. Letheby considered sufficient, as his observations induced the belief that this would be attended with advantage. It was admitted by all chemical philosophers that time was necessary for chemical action—in other words, that the completion of a chemical action was not instantaneous, the time required varying with the substances. The experience of sugar refiners, who of all manufacturers employed charcoal on the largest scale, was opposed to some of the views expressed as to the action of charcoal. The refiner was well aware that unless he allowed the sugar solution to pass slowly from the charcoal cistern, it would not be decolourized to the full extent, because time was required for the charcoal to exert its due effect. Besides, Professor Galloway, of the Royal College of Science, for Ireland, considered, from an extensive experience respecting the action of charcoal, that it was a serious error to suppose that the mere reburning of charcoal, after six months' use in the supposed purification of water, would render it as capable, or nearly so, of absorbing substances as at the commencement. The salts of lime, which it would have absorbed, must seriously interfere with its action; and, before burning the charcoal, these would have to be removed by acid and washing.

As the behaviour of permanganate of potash was not the same with different kinds of organic matter, it could not be used for the purpose of quantitative analysis; but as, when dealing with one and the same kind of organic matter, it might be fully relied on, it was very useful as a means of comparative estimation.

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[1] Upwards of 80,000 gallons per square foot in 24 hours, as compared with half a gallon per 4·38 square feet in 1 minute.

The experiments, of which the results were given in Table 2, were made with water collected at the same time and place; so that there was no difference in the condition of the organic matter it contained. By comparing the 2nd and 5th columns of this Table, it would be seen that, just as the first few gallons of filtered water contained less organic and other volatile matter than that found in the water before filtration, so was the amount of oxygen required to oxidize those quantities. When an equal quantity was found both in the original and filtered water, the amount of oxygen employed was the same; and when the quantity of organic and other volatile matter, in the filtered water, was in excess of that contained in the water before filtration, the amount of oxygen required to oxidize it was greater; so that the actual quantities of organic matter, whatever they were, might, without involving any appreciable error, be considered proportional to the figures in column 2. It could not be said that this proportion held good merely as long as it did not indicate an increase of organic matter in the filtered water, over that contained in the water before filtration; on the supposition, that the increase in quantity might be apparent only, and simply owing to some irregularity in the action of charcoal on nitrates. The fact that the residue of the seventh and subsequent gallons of filtered water became darker on ignition than that of the original water must be considered as indicating not only a worse state, but an increased quantity of organic matter. Upon examining the 5th column of the Table referred to, this would be found to be a matter of certainty; for, as the organic matter of these waters required more oxygen for its oxidation than that of the water before filtration, the quantity of organic matter itself must have been greater.

If the water employed in these experiments had been free from salts in solution, no doubt the charcoal would have continued to remove organic matter for a comparatively long period; and, possibly, after losing its removing power, there would have been no giving up of that which had been removed. But the water contained salts of lime and of magnesia, both of which were absorbed by the charcoal, probably with greater avidity, and certainly in a much larger quantity, than the organic matter. Again, as the surface attraction of animal charcoal for the former was greater than it was for the latter, after a while, when it could no longer act in absorbing them together, there was a displacement or giving up of organic matter, to make way for the salts; just as, by elective affinity, one substance might be displaced from its combination in order to make way for another. Dr. Letheby had asserted that animal charcoal acted on organic matter in water by bringing it into chemical union with the oxygen dissolved in the water, and thus destroying it; and that the passage of any water through this

material, without having its organic matter absorbed and oxidized, could only be owing to the want of sufficient free oxygen in the water to effect that oxidation. But the figures in the 5th column of Table 2, indicating, as they did, a varying amount of oxygen consumed, were at variance with such a statement; while the result of Mr. Chapman's experiments on animal charcoal must lead to a contrary conclusion. He had agitated some animal charcoal in water, and afterwards extracted from it the same quantity of organic matter as had been removed from the water. His experiments served to prove that its action did not consist in bringing the free oxygen dissolved in the water and the organic matter together, so as to convert the latter into carbonic acid, ammonia, and nitric acid—in fact, that the organic matter, instead of being oxidized by the charcoal, was merely absorbed, and mechanically retained within its pores. Dr. Letheby's subsequent communication, giving an account of recent experiments of short duration, could not be considered in the least to affect Mr. Chapman's statement, which was in accordance with established facts; for it was well known that organic alkaloids, and other substances, when absorbed by charcoal, could afterwards be dissolved out of it, actually unchanged. It was therefore submitted that the deductions to be drawn, with respect to the action of animal charcoal, as a filtering material, were, that it had not the oxidizing effect hitherto generally imagined, and as it did not act chemically, but simply by surface attraction and absorption, its removing effect became weakened by use, and finally ceased altogether. Further, that the time during which it could exert a removing effect depended not only on the quantity of water passed through, and the rate at which it was passed, but also on the nature of the water itself. If the water were exceedingly hard, the surfaces of the charcoal would become quickly coated, and its pores partially filled, by the absorption of those salts that produced hardness. As this must interfere with its action on other substances, its property of softening water was manifestly detrimental to it as a remover of organic matter: from which it followed that its effect on organic matter, at all times very limited, was greatest when the water dealt with contained the least amount of salts in solution. Lastly, as the surface attraction was not equally great for all substances, after a time some of those previously absorbed were in part displaced to make room for others which were more powerfully attracted. It was, probably, owing to this displacement that a portion of the organic matter at first removed was afterwards given up again.

As allusion had been made to the filtering substance termed 'Magnetic carbide,' he begged to say that the result of his experiments was not in accordance with what had been stated regarding the theory of its action, for the favourable indication of the re-

sidue, upon ignition, observed in the first few gallons of filtered water, was of short continuance. After a time it assumed a darker colour than that of the unfiltered water, besides which, according to Professor Wanklyn's and Mr. Chapman's test, the filtered water itself was found to contain as much albuminous organic matter as the water before filtration. Much had been said respecting the value of sand, and its suitability as a material for filter beds. Mention had also been made of how water might be freed from organic matter by Dr. Clark's process, but at the expense of its flavour. However, nothing had been elicited in the course of the discussion calculated to change his views with regard to the action of animal charcoal and filtering materials in general. He therefore felt justified in repeating that, as the use of filtration was very limited, and as all purifying processes should be regarded as mere temporary measures, pending the substitution of a pure for a contaminated supply, in his opinion the public ought cheerfully to undergo the necessary expense of procuring water not only in abundance, but in the greatest purity.

Mr. Gregory, Vice President, in closing the discussion, remarked that Mr. Byrne scarcely needed the assurance that the members fully appreciated the Paper he had brought before them, not only as an instance of an engineer devoting his attention to a scientific question of great interest to the profession, but also from its having led to a discussion which would leave much valuable information on record. The Institution always hailed the presence and co-operation of those who made exact science their study, and who, as on this occasion, had aided the discussion by their experience. If the practice of the engineer was not so exact as that of the experimental philosopher, and the minute analysis of the chemist appeared unnecessarily precise to the engineer, who dealt with larger figures and general results, it was well that even ideal perfection should sometimes be held up to the view of the practical man, like the stringent conditions of a specification, which might not always be followed to the letter, but which were maintained as a standard of excellence.

November 19, 1867.

JOHN FOWLER, President,
in the Chair.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Students of the Institution:—James Abernethy, jun., Francis Henry Ash-

HURST, EDWARD WILLIAM BAYLIS, EDWARD BAZALGETTE, NATHANIEL ST. BERNARD BEARDMORE, HENRY PERCY BOULNOIS, EDWIN LANE CAMPBELL, DAVID ALEXANDER CARR, FRANK CHEESMAN, JOHN CHARLES COODE, CHARLES EDWARD COWPER, JOHN HARCOMBE COX, JAMES MURRAY DOBSON, EDWIN NOEL EDDOWES, JOHN BREEDON EVERARD, CHARLES RICHARD FENWICK, CHARLES FLOOD, WALTER FOSTER, THOMAS ROBERT GAINSFORD, JOHN BARON HYDE GANDY, HERBERT THOMAS HARE, OWEN JONES, WILLIAM HUBERT KINCH, CHARLES HENRY GREY JENKINSON, CHARLES LE LIEVRE, FREDERICK GOTHER MANN, WILLIAM JOSEPH MARSHALL, HENRY THOMAS MUNDAY, JOHN NEWMAN, PHILIP ALGERNON HERBERT NOYES, WILLIAM PARTRIDGE, GEORGE JAMES PERRAM, JOHN KIRBY RODWELL, ROBERT BAXTER ROSE, WILLIAM SHIELD, GEORGE SHORTREDE, RICHARD HOMBERSLEY TOMLINS, DOUGLAS D'ARCY WILBERFORCE VEITCH, WILLIAM HENRY VENABLES, RICHARD WARBURTON, WALTER FRANK WATERFALL, THOMAS ROBERTS WATTS, HUBERT FREDERICK EARDLEY WILMOT, and FRANCIS WENTWORTH SMIJTH WINDHAM.

The discussion upon the Paper, No. 1,183, "On the Filtration of Water," occupied the whole evening, to the exclusion of any other subject.

November 26, 1867.

CHARLES HUTTON GREGORY, Vice-President, in the Chair.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Students of the Institution:—JOHN SIMEON BERGHEIM, EDWARD PEARCE BROWN, WALTER CHAPMAN BURDER, CHARLES CLOWES, JOHN THOMAS DENNISTON, the Hon. ALAN DE TATTON EGERTON, THOMAS CHARLES ELLIS, TRISTIE JAMES ELLIS, DAVID GRAVELL, JOHN WILLIAM DRINKWATER HARRISON, FRANK LIVESEY, ARTHUR ROBERT LUNGLEY, WILLIAM GEORGE MOORE, ARTHUR NEAME, THOMAS FARMER PARKES, HOWARD DEVENISH PEARSALL, the Hon. PHILIP JAMES STANHOPE, CLARENCE EDWARD TROTTER, ARTHUR JOSEPH WARING, and CHARLES STROUD WILLIAMS.

The discussion upon the Paper, No. 1,183, "On the Filtration of Water," occupied the whole evening, to the exclusion of any other subject.

December 3, 1867.

JOHN FOWLER, President,
in the Chair.

The following Candidates were balloted for and duly elected:—JOHN HALLEN ABBOTT, EDMUND COOPER, GEORGE GORDON, FRANCIS HAWKES, SAMUEL WAITE JOHNSON, DAVID LOGAN, WILLIAM LOW, JOHN STEVENSON MACINTYRE, JOHN MACKINLAY, WALTER MCCLELLAND, WILLIAM MENELAUS, JOHN PRESTON, THOMAS DAVID ROBERTS, ANTHONY SHERWOOD, JOHN FREDERICK SPENCER, WILLIAM HENRY WHEELER, JOHN SHELDON WILKINSON, and GEORGE HUSTWAIT WRIGHT, as Members; FREDERICK EDWARDS ARCHER, BENJAMIN BAKER, GORDON BIGSBY, Lieut., R.E., HERBERT BLAND BROWNING, THOMAS LONG COLLEY, CHARLES DAVIES, HERBERT LOUIS AUGUSTUS DAVIS, WILLIAM HENRY DELANO, THOMAS EASTMAN, JOHN MARSHALL EASTON, JOHN HYDE EDWARDS, Captain CHARLES WILSON FABER, CHARLES GANDON, JOHN HOWARD, THOMAS MANSON RYMER JONES, JAMES LIVESEY, WILLIAM LUKE, THOMAS EDWARD O'BRIEN, EDWARD CHARLES PATTERSON, WILLIAM SMALLPEICE, WILLIAM TIJOU, HENRY ELTZE VICTOR, and JAMES BIRDSALL WALTON, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—WILLIAM BERRELL, JABEZ CHURCH, jun., EDWARD CROMPTON, FREDERICK HARRY MORT, THOMAS REYNOLDS, WILLIAM TWEEDIE, and ANTONIO AUGUSTO VIEIRA.

No. 1,178.—"Description of the Victoria Bridge, on the line of the Victoria Station and Pimlico Railway."[1] By WILLIAM WILSON, M. Inst. C.E.

FOR many years after the introduction of the railway system, and even up to within a comparatively recent period, all the lines approaching the Metropolis from the south had their termini on the southern bank of the River Thames; and it was not until the year

[1] The discussion upon this and the following Paper was taken together, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

1857, that any attempt was made to relieve the public from the delay and inconvenience arising from the stations being so far removed from the centres of population, and so difficult of access. In that year the "Victoria Station and Pimlico Railway" was projected, with a view to supply the want which had been so long felt, by extending the railway then terminating in Battersea Fields to a more central position at the West End, at a point in Pimlico where the then existing Grosvenor Canal and Basin offered a favourable opportunity for obtaining a large and commodious station at a comparatively small cost. This railway, though only 1 mile in length, involved works of considerable magnitude and difficulty, the chief of which was the bridge for carrying the lines over the River Thames.

Although several years have elapsed since this bridge was completed and in operation, it has been thought that, from the magnitude of its dimensions and the novelty of some of the details, it may still possess sufficient interest to the Members of the Institution to entitle it to be recorded in the Minutes of Proceedings. With that view the accompanying drawings have been prepared, and are now presented, with the following detailed description:—

This bridge, which is generally known as the 'Victoria Bridge,' crosses the River Thames about 150 yards to the eastward of the Chelsea Suspension Bridge, at a point where the width of the waterway between the embankment walls is 740 feet. It consists of four segmental wrought-iron arches (Plate 2, Fig. 1), each having a span of 175 feet at the springing, with a rise of 17 feet 6 inches (being one-tenth of the span), and a clear headway of 22 feet above Trinity high-water level. At the northern end there is a land arch, or opening, of 70 feet span, crossing the Grosvenor Road, and on the southern shore there is a corresponding opening of 65 feet span, crossing the wharves of the Brighton Railway Company.

In regard to the spans, and the positions of the piers and abutments, the Engineer had little or no option, as the precise openings had already been settled by works which were then existing, or were in course of construction: thus, the line of the embankment walls necessarily determined the position of the faces of the abutments, while the close proximity of the Suspension Bridge rendered it essential that two of the piers of the railway bridge should coincide with those of the adjacent structure, and the centre opening of the Suspension Bridge being divided, gave four equal spans of 175 feet each, with three intermediate piers in the river.

The Foundations.

Before deciding on the exact form of the piers, or the manner in which they should be founded, careful borings were made at various

points across the bed of the river. The result of these showed that, at an average depth of about 30 feet below Trinity high-water level, the London clay existed in a comparatively solid and compact state, being covered with good strong and clean gravel, averaging about 7 feet in thickness in the middle and toward the southern shore, and increasing to 25 feet thick at the northern shore, caused by a sudden dip in the line of the clay and a more abrupt rise in the shelving surface.

A clause in the Act of Parliament, inserted by the Thames Conservancy, required that all the piers should be founded at such a depth as would admit of a deepening of the bed of the river to at least 30 feet below Trinity high-water level. The minimum headway was also fixed by the same authorities, and stringent regulations were imposed by them as to the extent of waterway to be occupied by the temporary works. After weighing all the different conditions and natural features, and giving the matter the fullest consideration, it was determined to build the piers and the abutments in solid masonry, and to found them upon the clay stratum by means of ordinary double-row timber coffer-dams.

The first operation was to dredge out from the bed of the river all the gravel down to the surface of the clay, for a breadth of about 100 feet, and extending across the entire width of water. By this means the pile-driving was greatly facilitated, and the Contractors obtained a stock of good and valuable material, which was used for the concrete in the foundations. The coffer-dams were then commenced, and were constructed of double rows of 12-inch piles, waled and strutted in the usual manner, and driven down to 4 feet below the foundation level, the spaces between the rows being filled with puddled clay. When the dams were completed and cleared of water, the whole area within was excavated to a depth of 40 feet below Trinity high-water level, being, on the average, about 10 feet into the clay, which at that depth was found to be exceedingly hard and compact, of a dark blue colour, and extending to a considerable depth below the foundation level. For the abutments a similar operation was followed, the dams (except as to dimensions) being constructed in precisely the same manner. On the south side, the clay being rather nearer the surface, the foundation was of less depth, and the ground at the back being good, the dam was driven on the river side only, and abutted against the embankment walls. But on the north side the line of clay was so much lower, that it was necessary to carry down the abutment to a depth of 46 feet 6 inches below Trinity high-water level, in order to reach a solid foundation, and that, coupled with a large flow of water from the land, required the dam to be entirely closed on all sides. In getting in this foundation considerable difficulties were encountered; the nature of the material

excavated was so loose, and the amount of water was so great, that it required the combined power of eight pumps, capable of lifting 8,000 gallons per minute, to overcome it. The water, as it accumulated, was collected in a well 6 feet square, sunk within the dam, and carried up through the lower beds of concrete, which was filled into the entire space, and brought up to the same level as the base of the piers; and after the overflow was overcome, at a proper altitude, a box to fit the aperture was made and filled with concrete, then dropped into the opening, and covered with a heavy stone slab.

The Masonry.

The excavations for the river piers having been carried down to the required depth in the clay, the foundations were enclosed by permanent sheet piles, 15 feet long and 6 inches thick, driven to a depth of 8 feet below the lowest foundation level. (Plate 2, Figs. 2 and 3.) Within this sheeting a bed of cement concrete, 4 feet in thickness, was formed, and on that the masonry of the pier was commenced, the concrete being carried up to the top of the sheet piles round the entire circumference of the piers. The footings consisted of two courses of Yorkshire rag landings, each 12 inches thick, each stone being not less than 8 feet square, and laid so as to break joint in all directions, the width of the lower course being 25 feet, and the second course stepping off 1 foot on each side. From the footings up to the level of 4 feet below low water, the piers were built entirely of brickwork in lias mortar, stepped back every foot in height to form the curved batter, and thence up to the level of high water they were faced with rock-faced Portland roach stone, in courses of 1 foot 6 inches each, 3 feet in width on the beds, with one through course half way up. The core or backing, composed of pavior bricks, was set in lias mortar, and the cutwaters, caps, springers, and all the masonry above high water, were faced with tool-dressed Bramley Fall stone. The width of the pier at the springing line was 12 feet 4 inches, and from the extrados of the arch to the level of the cornice the width was 10 feet.

The abutments were carried down to the same depth into the clay as the piers, and commenced with a base of cement concrete 44 feet wide, and continued at the same width up to the level of 32 feet below high water; from thence to the springing line the width was reduced to 41 feet 6 inches, and the whole composed of lias lime concrete, with three layers or bonding courses of brickwork in cement, each course being 2 feet 6 inches thick, running through the entire width. The facing next the river from the level of low water to the springing line was of Portland roach stone, similar to the piers, and backed with 8 feet of brickwork in cement. From the springing upwards the width of the abutment was 18 feet, the

walls, which were 4 feet thick, being faced on each side with Bramley Fall stone.

All the concrete used in the work was composed of Thames gravel, which had been dredged from the river in preparing the site for the dams, the greatest care being taken to select that which was clean and sharp; after being screened and freed from excess of sand, it was mixed in the proportion of one measure of cement or lias lime to six measures of gravel.

The brickwork in the piers was composed of the best pavior bricks, 'Cowley stocks' being used in the abutments and in the remaining parts of the works. All brickwork under low water was set in cement, and all above that level was built in Greaves' blue lias mortar, mixed in the proportion of one of lime to two of sand.

The Superstructure.

The superstructure of each of the four principal openings consists of six wrought-iron arched girders (Figs. 7 and 8), springing from cast-iron bed plates fixed to the masonry (Figs. 11 and 12). Horizontal girders, resting on the piers and on the abutments, and riveted to the arch near the crown, form the longitudinal bearers for the roadway. The spandrils, or intermediate spaces between the arched ribs and the horizontal girders, are each filled in with a wrought-iron framework radiating from the arch; and between the horizontal bearers cross girders, for carrying the roadway, are fixed at distances averaging about 3 feet apart.

As the ironwork for each of the four principal openings is precisely similar in every respect, a detailed description of one span will suffice to explain the whole:—

As before stated, each arch is composed of six ribs, carrying two lines of mixed gauge railway. All the ribs are similar in construction, but vary in sectional area; they are **I** shaped, the top and bottom tables and the central web being composed of flat plates connected together longitudinally by angle irons, and vertically by **T** iron stiffening pieces covering the joints in the web at every 6 feet apart. The two central ribs, which may each have to carry half the load on one line of rails, have each a total sectional area of 80 inches, as follows:—

Top table	1 plate	$7\frac{1}{2}$ in. × $\frac{5}{8}$ in.	= 30 inches.
	1 plate	18 in. × $1\frac{1}{32}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
Web	1 plate	40 in. × $\frac{1}{2}$ in.	= 20 ,,
Bottom table . . .	1 plate	$7\frac{1}{2}$ in. × $\frac{5}{8}$ in.	= 30 ,,
	1 plate	18 in. × $1\frac{1}{32}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
Total . . .			80 inches.

No. 2, or the first inner ribs have each an area of 71·2 inches, as follows:—

Top table	1 plate	$7\frac{1}{2}$ in. × $\frac{5}{8}$ in.	= 25·6 inches.
	1 plate	18 in. × $\frac{25}{32}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
Web	1 plate	40 in. × $\frac{1}{2}$ in.	= 20·0 ,,
Bottom table . . .	1 plate	$7\frac{1}{2}$ in. × $\frac{5}{8}$ in.	= 25·6 ,,
	1 plate	18 in. × $\frac{25}{32}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
		Total . . .	71·2 inches.

and No. 3, the outer or face ribs have each an area of 53·4 inches, as follows:—

Top table	1 plate	15 in. × $\frac{5}{8}$ in.	= 19·2 inches.
	1 plate	$7\frac{1}{2}$ in. × $\frac{3}{8}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
Web	1 plate	40 in. × $\frac{3}{8}$ in.	= 15·0 ,,
Bottom table . . .	1 plate	15 in. × $\frac{5}{8}$ in.	= 19·2 ,,
	1 plate	$7\frac{1}{2}$ in. × $\frac{3}{8}$ in.	
	2 angles	7 in. × $\frac{1}{2}$ in.	
		Total . . .	53·4 inches.

Each arched girder is, for facility of construction, divided into five segments, and each pair of segments is connected by twelve bolts, $1\frac{1}{4}$ inch in section, passing through the angle irons, which are returned and welded at the ends, and through transverse flat iron plates which extend the entire width of the pair of girders; transverse covering plates, 9 inches by $\frac{1}{2}$ an inch in section, are riveted to the upper and lower flanges of each rib at intervals of about 6 feet apart.

The horizontal girders which stretch from arch to arch, and bear upon bed plates fixed on the piers and on the abutments, are similarly constructed to the arched ribs. They are each 3 feet in depth, and are composed of flat plates forming top and bottom tables, with a central web, all connected by angle irons, and stiffened by T iron stiffening bars, covering the vertical joints at every 6 feet, the top line coinciding with the extrados of the segment; the horizontal girder dies away in the crown of the arch, to which it is firmly riveted. The four inner girders, which carry the roadway, are all exactly similar and of equal sectional area. The top table is composed of two plates, one measuring 12 inches by 1 inch, and the other $6\frac{1}{2}$ inches by $\frac{1}{2}$ inch, connected to the web by two angle irons, each 3 inches by 3 inches by $\frac{1}{2}$ inch, giving a total area of 20·75 inches; the bottom table is composed of plates of the same dimensions, giving an equal area; and the web has a depth of 34 inches by $\frac{3}{8}$ inch, equal to 12·75 inches section, the whole making a total sectional area of 54·25 inches. The external or face girders are of

the same depth, viz., 3 feet, and consist of one top plate, 25 inches by $\frac{1}{2}$ inch, which projects outward from the web, and forms the lower member of the wrought-iron moulded cornice; this is connected to the web by two angle irons, each 3 inches by 3 inches by $\frac{1}{2}$ inch; the web plate measures $35\frac{1}{2}$ inches by $\frac{3}{8}$ inch, and is connected by angle irons to the bottom table, which is composed of one plate, $9\frac{1}{2}$ inches by $\frac{1}{2}$ inch, the total sectional area being 38·8 inches. Like the arched ribs, the horizontal girders are also constructed in pairs, the two being connected by flat-plate diaphragms $\frac{5}{16}$ inch thick, riveted to the T iron covering pieces at distances averaging about 6 feet apart; covering plates, 9 inches wide by $\frac{1}{2}$ inch thick, are also riveted to the top and bottom flanges of each pair, as in the case of the arched ribs.

The horizontal girders are continuous over the entire length of the four principal openings, and in the centre of each pier a stiff expansion joint is provided (Figs. 9 and 10), for the purpose of equalizing the strains under different temperatures. These joints are formed by two plates, each 6 feet in length and $\frac{3}{8}$ inch thick, one being fixed on each side of the web plate and covering the open joint. Twenty bolts, each $1\frac{1}{8}$ inch in diameter, pass through the three plates, the bolt holes in the side plates being slotted out to $2\frac{1}{2}$ inches, allowing a play of $\frac{5}{16}$ inch on each side of the bolts. At the ends of the covering plates angle irons, 4 inches by 4 inches by $\frac{5}{8}$ inch, are riveted; and a corresponding angle iron is also attached to the web of the girder, a space of $1\frac{1}{2}$ inch being left between the two angle irons, which are joined by seven bolts each $1\frac{1}{2}$ inch in diameter; these bolts are provided with two circular vulcanized India-rubber washers, $1\frac{1}{4}$ inch in thickness, and 3 inches in diameter. Cover plates are also attached to the top flange of the girder; the upper plate is 6 feet long by 12 inches wide, and underneath there are two plates, each $2\frac{3}{4}$ inches wide, running on each side of the angle iron; these are attached by thirty-six bolts, each $1\frac{1}{8}$ inch in diameter, the bolt holes being all slotted out longitudinally to $2\frac{1}{2}$ inches, permitting the same amount of motion as the bolts in the side plates. The joints were made and the bolts screwed up at a mean temperature of 60°, and the girders, which rest on bed plates on each side of the open joint, are perfectly free to expand or contract, the continuity of strain being always preserved by the elasticity of the India-rubber washers.

Between the horizontal girders and the arched ribs the spandrils are filled in with a wrought-iron framework radiating from the arch. The four inner sets are each composed of two T irons, measuring 5 inches by 3 inches by $\frac{1}{2}$ inch, placed back to back, and riveted through flat plates varying in thickness in proportion to their lengths. The T irons are cranked at the angles, and are

riveted to and form part of the upper table of the rib, and the lower table of the horizontal girder. These radiating struts are intersected longitudinally by a stiffening bar, 6 inches by $\frac{1}{2}$ inch in section, which passes through the centre of each of the spandrils, and is riveted to the radiating bars at the points of intersection. In the outer spandrils the framework is also composed of T irons, measuring 5 inches by 3 inches by $\frac{1}{2}$ inch, riveted together back to back, in the same manner as the others; but in this case the flat bars are omitted, and the T irons are cranked and forged into separate frames set to the shape of each section, so as to form an ornamental face and present a uniform smooth surface, the riveting in all the face work being countersunk.

Each pair of arched ribs springs from two cast-iron frames, resting on and bolted through the masonry of the piers and abutments (Figs. 11 and 12). A segmental cast-iron shoe is bolted to the end of each rib, and rests in a corresponding concave bearer which works loose in the frame, and is provided with wrought-steel keys and cotters for adjusting it in its position. The frames to receive the shoes are each 4 feet 8 inches in width, 4 feet long, and 3 feet 8 inches in depth; the thickness of metal in the base and sides is $1\frac{1}{2}$ inch; the back, where the loose shoe rests, is $2\frac{1}{2}$ inches thick, and is further strengthened by two strong flanges projecting 4 inches into the masonry. The cast-iron shoe and bearer are each of the same width as the end of the rib, and the metal is uniformly $2\frac{1}{2}$ inches in thickness throughout; the surfaces are all accurately turned and planed, so as to insure the most perfect contact in every part. There are two keys and four cotters to each rib. The keys are 5 feet 4 inches in length, 8 inches wide at the top tapering to 4 inches at the bottom, and 2 inches thick. By this arrangement the whole compressive strain is distributed over the entire sectional area of the arch, whatever may be the temperature. As the bearers moved freely on the beds with a play of about 2 inches, regulated by the taper of the keys and cotters, they greatly facilitated the adjustment of the arches in their position; for however much care may be bestowed in setting out and building arches of such great length, it is exceedingly difficult to get them so accurately constructed, as to fit precisely and bear truly on the springing, so that the loads may be uniformly distributed. By means however of this arrangement of keys and cotters, the whole was driven up after the ribs were fixed in place, so as to secure that uniform distribution of strains on which so much of the strength of arches of this character depends.

It has already been explained how the ribs and horizontal bearers are connected together, so as to form, as it were, two ribs and two bearers into one box-girder; in addition, there was a complete

system of vertical and transverse bracing and strutting to both the girders and the spandril-filling. Between each pair of the arched girders, at the first junction of the segments, a strong wrought-iron cross stay, 3 feet 6 inches in depth, was formed, by continuing the flat plate diaphragm through the entire width of each roadway, so as to unite the whole of the six ribs firmly together at that point. This stay was formed of plates $\frac{1}{2}$ inch thick, stiffened by top and bottom tables, 9 inches by $\frac{1}{2}$ inch, united by four angle irons, each 3 inches by 3 inches by $\frac{1}{2}$ inch. Additional strength was given to this stay by stout gusset plates, uniting it with the top and bottom tables of the arch. Strong wrought-iron rolled beams, 10 inches in depth, with top and bottom flanges 5 inches wide and $\frac{1}{2}$ inch thick, were also fixed between each pair of ribs at distances of 12 feet apart throughout the whole length of the arch. Each pair of spandrils was united by two horizontal ties, 3 inches by $\frac{1}{2}$ inch in section, riveted to each of the radiating struts, and placed 4 feet apart; the space between was crossed by a pair of diagonals of the same section, forming a complete brace to each pair of the radiating bars. From the top table of the arch to the under side of the opposite horizontal girder, diagonal ties of round iron, 2 inches in diameter, were fixed in the line of each radiating strut; the ends being forged to clip the flanges of the girders, to which they were firmly bolted, by four bolts, each $1\frac{1}{4}$ inch in diameter, and each pair was provided with adjusting plates and keys at the points of intersection.

The roadway throughout the entire length of the viaduct was carried on rolled wrought-iron cross beams, 10 inches deep by $\frac{1}{2}$ inch thick, with top and bottom flanges 5 inches in width by $\frac{3}{4}$ inch thick. These beams were provided with angle pieces at each end, and were bolted through the webs of the horizontal and the arched girders with bolts $6\frac{3}{4}$ inches in diameter, every alternate bearer continuing through the entire width from outside to outside. As these cross girders were placed over the radial spandril bars, the spaces between them were necessarily unequal, but they averaged throughout about 3 feet.

In consequence of the steepness of the approaches on each side of the bridge, the gradients of which were 1 in 60, it was of the utmost importance that the level of the rails across the bridge should be kept as low as possible. The cross beams were therefore fixed so as to rest on the bottom tables of the horizontal girders, and at the crown of the arch on strong angle pieces riveted to the web of the arched rib. Between the cross beams a close timber flooring, 6 inches in thickness, was laid, resting on the bottom flanges and butting lightly up against the web. The longitudinal sleepers, 14 inches by 7 inches in section, which carried the rails, were connected by transomes and tie-bars 11 feet apart,

and were laid on a layer of 6 inches of 'Burnetized' sawdust, which intervened between the timber floor and the gravel ballast.

The 70 feet land opening at the north end was required to cross the main road leading to the Suspension Bridge, which was being formed at the time the Victoria Bridge was building. The officials of the Board of Works were excessively stringent in their requirements, and clauses were inserted by them in the Act of Parliament prohibiting any interference with the levels of the road, and requiring a span of 70 feet with a minimum headway of 16 feet throughout the entire width. To comply with these engagements, it was necessary to carry the roadway on horizontal girders, two in the centre and two on each face; these girders were parallel, and each pair was connected together in the same manner as the arched ribs. The four inner girders were all exactly similar in every respect. The depth was 4 feet 7 inches, the top and bottom tables were each 18 inches wide, and contained a sectional area of 57½ inches, made up of three plates, each 18 inches wide by 1 inch thick, and angle irons 3½ inches by 3½ inches by ½ inch. The external or face girders were each 4 feet 9 inches deep, the top and bottom tables being each 9 inches by 1 inch.

Wrought-iron rolled cross beams, of the same form and section as those on the arches, were used for carrying the roadway; they rested on the bottom tables of the main beams, and were cut out 3 inches, in order to bring the lower flange to the same level as the horizontal girder over the arch. Each alternate cross beam was carried right through from outside to outside, and covering plates, 6 inches wide by ½ inch thick, were riveted to the bottom of the cross girders, forming a complete transverse connection. Diaphragm plates ¼ inch thick, riveted to the T covers, connected each pair of main girders at every 6 feet in length, and they were further stiffened by cover plates 6 inches by ½ inch, riveted to the upper and lower flanges of each pair, midway between the diaphragms. Between the cross girders, flooring plates ¼ inch thick were fixed and riveted to the bottom table for the purpose of forming a watertight ceiling to the roadway. The upper surface of the plates was covered with 1 inch of asphalte, and the water was led off to the abutment through holes cut in the centre of the web of the cross girders.

On the outer face of the external horizontal girders, throughout the entire length of the viaduct, a fascia was formed by projecting the top table. This was composed of plates ¼ inch thick, curved and bent to the proper form, connected by angle irons, and with countersunk rivets so as to make an ornamental cornice. Immediately above, and bolted to the same girder, cast-iron standards 6 feet apart were fixed, the spaces between being filled in with a moulded cast-iron panelled plinth, 3 feet 6 inches high, sur-

mounted by an ornamental cast-iron parapet railing, capped with a moulded hardwood handrail.

The whole of the wrought iron used in the bridge was composed of 'crown plates,' manufactured by the Monkbridge Iron Company, Leeds, and the cross girders and angle irons were rolled at the works of the Butterley Company. All the plate iron used throughout the bridge was subject to the most rigid and careful testing.

The joints of the segments, and all the vertical and horizontal joints in the plates, were accurately machine-planed, so as to insure the most perfect contact over the entire surface. The riveting generally throughout the work was pitched at 4 inches apart, and in the facework the rivets were neatly countersunk, so as to present a uniform smooth surface.

The quantities of the different materials employed in the erection of the entire structure are :—

197,800	cubic feet timber used for temporary purposes.
37	tons wrought iron in dams.
16,800	cubic feet timber in floors (permanent).
10,700	,, York landings.
5,750	cubic yards concrete.
6,500	,, brickwork.
23,587	cubic feet Portland roach stone.
57,205	,, Bramley Fall stone.
1,349	tons wrought iron.
204	,, cast iron.
15½	,, steel keys and cotters.

The total cost of the bridge, including the land arches and abutments, was about £84,000. The superficial area of the roadway between the parapets is 31,690 feet; consequently the cost per superficial foot is £2 13*s*. The total length being 930 feet, the cost per lineal foot for each line of railway was £45 3*s*.

The whole of the works were designed by Mr. John Fowler, President Inst. C.E., the Engineer in Chief to the Company, and they were carried out under his immediate supervision by the Author. Mr. John Kelk, M.P., Assoc. Inst. C.E., was the Contractor for the works, and the ironwork was sublet by him to Messrs. Bray and Waddington, of the New Docks Works, Leeds.

The first stone of the bridge was laid on the 9th of June, 1859, and the first train passed over on the 9th of June, 1860; thus, only twelve months were occupied in the erection of this important structure. The rapidity with which the work was executed was due in a great measure to the energy of the Contractor and the arrangements he made for carrying out the contract, as well as to the way in which the different parts of the ironwork were designed. By dividing the arch into segments, the ribs were fixed with great facility; no centering was required, and all the timber necessary, beyond the gantry erected for setting the masonry, was a

simple upright support under each segment joint. No part of the superstructure was of greater weight than could be easily lifted by the ordinary travelling cranes, so that the moment the masonry was ready to receive the ribs and girders (which had been all built and fitted at Leeds) they were lifted into their places and secured.

After the arches were erected and the supports were removed, the whole of the ironwork was subjected to a severe testing of its strength. This was done by loading each arch with a moving weight of 350 tons placed on the two lines of way, being equal to a load of 1 ton per lineal foot on each pair of rails. The deflections were taken with the greatest accuracy, by fixed gauges underneath and by levelling from above, the results in each case, when compared, being found perfectly to coincide. Commencing at the north end, the load was placed first on the 70 feet opening, extending over the abutment up to the centre of the first arch; the deflection of the 70-feet girders was 0·48 inch in the centre, the greatest deflection in the arch being at a point 60 feet from the abutment, and amounting to 0·58 inch and 0·38 inch at the crown, and the horizontal girder showed a deflection of 0·72 inch at 60 feet from the abutment; the same experiment produced a rise in the adjoining arch to the extent of 0·12 inch at the crown, the third and fourth arches showing no movement. The next experiment was made by moving the whole load over the entire span of the first arch; the deflection produced by this was 0·71 inch at the crown of arch, and 0·56 inch at points 35 feet on each side. The deflection of the horizontal girder was regular throughout its entire length, commencing at 0 on the piers, and gradually increasing up to 0·71 inch at the centre; the adjoining arch, which was unloaded, showed a rise in the centre of 0·16 inch and 0·17 inch at 30 feet nearer the load; the horizontal girder also rose to the extent of 0·24 inch midway between the pier and the centre of the arch, no change being perceptible in the third and fourth arches. The load was then passed on to the centre of the first pier and extended from crown to crown of the first and second arches; this produced a depression of 0·41 inch at the crown of each arch, and 0·36 inch and 0·24 inch in the horizontal girders midway between the piers and the centres of the arch. The second arch was then subjected to the whole strain, and the deflection noted was 1·02 inch at the crown of arch and 0·76 inch at 30 feet on each side; the horizontal girder deflecting 0·12 inch midway between the pier and the crown. The two adjoining arches rose 0·10 inch in the centre, and the greatest rise in the horizontal girder was at 30 feet from the pier, where it amounted to 0·24 inch. The same load equally distributed over the third arch produced a deflection of 1·08 inch in centre, and in the fourth arch it amounted to

0·96 inch. The loads were then removed, and a train of engines weighing 1 ton per lineal foot, and 175 feet in length, was run at full speed over one line of way; this produced a deflection of 0·40 inch in the first arch, 0·48 inch in the second, and 0·45 inch in the third and fourth arches. After the experiments were completed, the arches and horizontal girders were carefully gauged, and the permanent set was found to be so small as to be scarcely appreciable; the readings being 0·10 inch in the first arch, 0·10 inch in the second, and 0·12 inch in the third and fourth arches.

In conclusion, the Author has only to remark that, in the foregoing description, he has confined himself strictly to a detailed account of the Victoria Bridge as it exists, and he believes that in this work utility and ornament have been successfully combined. Every part of the ironwork takes its fair share of duty, and the extreme strains, produced by the most unfavourable combination of circumstances, in no case exceeds $4\frac{1}{2}$ tons per inch of section.

The Paper is illustrated by a series of Drawings, from which Plate 2 has been compiled.

APPENDIX.

VICTORIA BRIDGE.—Summary of Quantities of Wrought Iron.

	Wrought Iron.	Tons.	cwt.	qrs.	lbs.	Tons.	cwt.	qrs.	lbs.
8	Central arched ribs	22	2	3	26	177	3	3	12
8	Ditto, ditto	22	0	1	22	176	3	2	8
8	Outside arched ribs	19	4	0	6	153	12	1	20
8	Outside horizontal girders	10	3	1	1	81	6	0	8
16	Inner horizontal girders	11	6	0	8	180	17	0	16
8	Extra pieces in abutments	0	15	1	12	6	5	0	0
16	Inner spandrils	7	2	2	22	114	3	0	16
8	Outer spandrils	5	9	3	27	43	19	3	20
224	Cross girders E	0	4	1	15	49	2	0	0
256	Ditto, ditto D	0	3	2	21	47	4	0	0
116	Ditto, ditto F	0	0	2	14	3	12	2	0
232	Ditto, ditto F	0	0	2	21	7	19	2	0
128	Cover plates under cross girders	0	2	2	20	17	2	3	12
	Cross girders to arched ribs					11	19	1	19
	Diagonal stays					9	18	1	4
	Diagonal tie bars					8	13	0	0
	Joint plates to segments					5	0	2	24
	Cornice to river arch					63	7	2	8
8	Inner girders for 70-feet opening	15	13	0	16	125	5	0	16
4	Outer girders	6	7	3	15	25	11	2	4
	Cross girders					35	16	3	4
	Cornice					10	1	0	0
	Filling pieces, iron flooring, bolts, ties, &c.					15	10	0	0
	Total tons					1,348	14	0	0

No. 1,176.—"On the Widening of the Victoria Bridge and Approaches to the Victoria Station, and on New Railways at Battersea."[1] By CHARLES DOUGLAS FOX, M. Inst. C.E.

THE system of railways designed by Sir Charles Fox, M. Inst. C.E., in the year 1862, for the purpose of improving the access to the Victoria Station, by providing additional lines, and avoiding the sharp curves and steep gradients of the then existing railways, comprises the following works:—

The widening of the Victoria Station and Pimlico Railway, and the widening of the Victoria Bridge over the Thames, carried out jointly by the London, Brighton, and South Coast, and the London, Chatham, and Dover Railway Companies.

The high-level line, from the south end of the Victoria Bridge to near Clapham Junction, with a branch to Wandsworth Road, carried out by the London, Brighton, and South Coast Railway Company.

The diversion and raising of the West End and Crystal Palace, and West London Extension Railways, the Longhedge Junction Railway, the high-level line from the Victoria Bridge to Wandsworth Road, and the two low-level lines from the same bridge to Stewart's Lane, carried out by the London, Chatham, and Dover Railway Company.

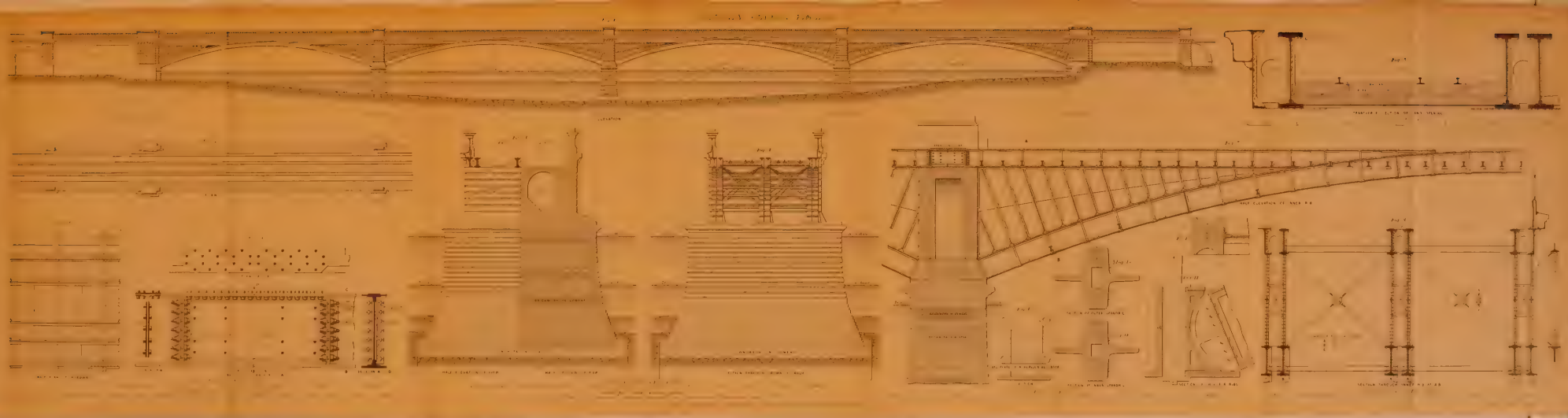
The connecting link between the London and South Western, and the London, Chatham, and Dover systems at Clapham Junction, carried out by the London and South Western Railway Company.

Plate 6, Fig. 1, shows the railways in this district as they existed in 1862, and Plate 6, Fig. 2, as they exist at present. The Author desires, as briefly as possible, to lay before the Institution a description of the more important features of this system of railways, which has been carried out in accordance with a comprehensive plan, determined upon from the commencement.

WIDENING OF THE VICTORIA STATION AND PIMLICO RAILWAY.

This railway was originally constructed by Mr. John Fowler (President Inst. C.E.), for two lines of way of mixed gauge; but the increasing traffic of the three Companies which already use this terminus, viz., the Brighton, the London, Chatham, and Dover, and the Great Western Companies, and the anticipation of other Companies desiring also to have access to it, rendered it essential to provide

[1] The discussion upon this and the preceding Paper was taken together, and occupied portions of four evenings, but an abstract of the whole is given consecutively.



additional lines, and to separate entirely the traffic of the first from that of the two last-named Companies. It was therefore determined to remove the broad gauge from the two existing lines, and to devote them, as also one additional line of narrow gauge, to be laid down beside them, entirely to the traffic of the London, Brighton and South Coast Company, and to construct for the London, Chatham, and Dover, and the Great Western traffic, three mixed and one narrow-gauge line. The works on this length of three-quarters of a mile are of an ordinary character, being in cutting between retaining walls for the greater portion of the distance, with three over-bridges for roads—one of them, Ebury Bridge, being fan-shaped in plan. The chief work was the removal of the retaining wall from one side of the existing railway—an operation of some difficulty, where, on account of trains so frequently passing, blasting could not be employed. It was also necessary, without interference with the constant traffic, to substitute a girder bridge in the place of an arch over the existing line, which was itself receiving a portion of the thrust of an arch over an adjoining canal. This was safely accomplished by cutting away a narrow strip of the arch, and inserting one girder at a time. In order to prevent annoyance to adjoining householders, the line was required to be roofed over; and this involved the use of heavy trusses, somewhat similar to those adopted for the original line. These are, in some instances, 120 feet span, 10 feet deep, and weigh 17 tons each. In several cases they act as cantilevers, and support one end of the original trusses. Cast-iron gutters are suspended from the bottom flanges of these trusses by means of bolts, and these gutters carry the light wrought-iron principals of the roof, which are generally 50 feet span, and placed 8 feet 4 inches apart. The purlins, louvres, and gables are of wood, the last-named being left unglazed, to allow of the escape of steam. To avoid the great breakage of glass caused by the blast of the locomotives, the lower half of the roof is covered with Vieille Montagne zinc, No. 15 gauge, fixed on wooden rolls, the upper half being glazed. The London, Chatham, and Dover portion of the station has been greatly enlarged. The signal arrangements for the whole station have been remodelled, and now consist of five boxes, fitted with apparatus, upon Messrs. Saxby and Farmer's principle, having altogether two hundred and thirty-five levers.

Widening of the Victoria Bridge.

It was the original intention to have constructed an independent bridge to carry three lines of way, for the London, Chatham, and Dover traffic; but, it having been determined to add, at the same time, a third line for the London, Brighton, and South Coast Railway Com-

pany, it became necessary to make arrangements for joining up the new work with the Victoria Bridge.

The new bridge, in common with the original one, consists of four river spans, of 175 feet each, having arched ribs, with a rise of 17 feet 6 inches, giving a headway above Trinity high-water mark of 22 feet, and of two land openings, carried by plate girders, one of 70 feet, the other of 65 feet span. Its width, from the outside of the original bridge to the parapet, is 100 feet, giving, with the old work, one structure, 132 feet 6 inches wide between the parapets. The total length of the piers and abutments, just below the springing, is 158 feet. It is constructed to carry at present, with the existing lines, three lines of narrow gauge for the Brighton traffic, and two mixed and two narrow-gauge lines for the Chatham and Dover, and the Great Western traffic; and also two platforms, one 24 feet, the other 12 feet wide, which are in connection with the stations at either end. The portion of the bridge carrying these platforms is, however, so arranged as to admit, upon the addition of one more rib only in each span, of three more narrow-gauge lines, so that the two bridges together, as now united, are capable of carrying ten lines of way, eight narrow and two mixed gauge.

The excavations for the abutments were got out by means of double cofferdams of whole timbers on the river front, continued on the land side by single rows of the same. The general length of the piles was 40 feet. The puddle, which was 5 feet in thickness, was brought from the River Medway. Woodford's centrifugal pumps were used with much success for both the abutments and the piers. The northern abutment was carried down to a depth of 30 feet, and the southern abutment to a depth of 26 feet below Trinity high-water mark, being in each case founded on good hard gravel. The whole of the space excavated was covered with cement concrete, 3 feet thick, filled close up to the inner row of piles all round; on this brickwork in cement 3 feet thick was laid, and then outside and cross walls of brick in cement were carried up, the pockets being filled with lime concrete. (Plate 3, Figs. 7 and 8). The inner row of piles on the river face was cut off just above the concrete, and all the other piles were drawn. In consequence of the proximity of the original bridge, it was impossible to drive the cofferdams so as to include the whole of the work, and a portion of the face is therefore carried on strong cast-iron girders, put in at low-water mark, resting at one end on the old, and at the other on the new work. By the use of cement, and the care taken to keep the joints thin, the abutments, though bonded up with the old work, have not shown the least sign of movement.

Some difficulty was experienced in designing the foundations for the piers, in consequence of the sheet piling used for the former

cofferdams projecting considerably beyond the nose of the piers. The foundations of each pier were carried down by means of four cast-iron cylinders (Plate 3, Figs. 3, 4, 5, and 6), each 21 feet internal diameter and 24 feet long, cast in segments 8 feet in length, and fitted together with flanges. These cylinders were $1\frac{1}{4}$ inch only in thickness, except for about 2 feet at the bottom, where the metal was swelled out. Temporary wrought-iron cylinders, 19 feet in diameter, were used for 28 feet 6 inches at the top. (Plate 4, Figs. 21, 22, and 23). The joint between the temporary and the permanent cylinders was made by allowing the edge of the plate forming the bottom of the former to rest upon a piece of india-rubber inserted in a groove in the upper segments of the latter; this was found in every case to be perfectly water-tight. About 100 tons of kentledge were used in sinking the cylinders; this was laid upon stages slung within the cylinders, as being less liable to tilt the cylinders than when placed outside, and more easily thrown off when the requisite depth was reached. The bed of the river having been levelled by bag and spoon, the cast-iron cylinders were put together and lowered into their places; the wrought-iron cylinder was then attached, and the cylinders descended by their own weight assisted by that of the kentledge, and by clearing round the inside edge by the bag and spoon till the London clay was reached, when the water was pumped out, and men put in to excavate, following the cylinder as it descended. The whole of the cylinders were sunk without difficulty to an average depth of 45 feet below Trinity high-water mark, of which 13 feet were into the London clay, the total time occupied in sinking being on an average eight days. After the water was once pumped out they were so dry that water had to be laid on to properly wet the bricks. The cylinders were filled with cement concrete for a depth of 12 feet, and then with brick in cement up to low-water mark. The brickwork in each of the cylinders nearest to the old work was then loaded with 1,250 tons, that in the next two with 1,000 tons, and that in the outer cylinder with 750 tons, left on for a week. This was done in order to prevent cracks in the work when bonded up with the other bridge. The greatest movement under this load was $\frac{7}{8}$ths of an inch, with a slight return when the weight was removed. If the bridge were loaded all over with locomotives, the greatest weight upon the brickwork in the cylinders at low-water mark would be nearly 6 tons per superficial foot and upon the clay at the bottom 5 tons per foot, not deducting for friction. This test having been completed, the first course of masonry was laid in the cylinders, and the wrought-iron cylinders and the upper ring of the cast-iron cylinders was removed. Strong framework of cast iron was then fixed to carry the stonework face between the cylinders, a similar framework, though of greater span, forming the connection on the face

between the old and the new work. The weight of the superstructure is, however, mainly carried by strong arches of brick in cement turned between the cylinders in the hearting of the piers, which from this level to the springing line are of solid brickwork in cement faced with masonry. It will thus be seen that the new piers, though founded on cylinders, form, above low-water mark, one continuous face of masonry with those of the original bridge, altogether 158 feet in length. The gantries for the piers and for the erection of the superstructure were naturally very extensive, containing 286,000 cubic feet of timber, including that in the coffer-dams, but they do not call for special remark. The abutments and the piers are faced from low-water to high-water mark with Portland roach stone, and above that level, with Bramley Fall ashlar, except between the spandrils, where gault bricks are used. The stonework removed from the face of the other bridge was worked in again as much as possible. A bedding course of Bramley Fall stone was laid right through the piers for each rib, and upon this was fixed a cast-iron skewback and standard (Plate 4, Fig. 9), of the whole width of the pier, running up to and connected with the underside of the horizontal girder forming the top member of the arch. Cast-iron skewbacks and standards were also fixed in the abutments.

The superstructure of each of the river spans is precisely the same, and consists of eight main ribs, with provision for a ninth (Plate 3, Fig. 3); of these the rib nearest the existing bridge is only one-half the strength of the others, which are each calculated to carry a single line of way. These arched ribs are of wrought iron 3 feet 4 inches deep and 1 foot 6 inches wide in the flanges; but for 38 feet in the centre of the span they merge into one with the horizontal girders, thus giving a total depth at the centre of 4 feet 6 inches. (Plate 4, Fig. 9). The flanges of the ribs diminish gradually from a thickness of 3 inches at the centre to $1\frac{1}{2}$ inch at the springing, the webs being of $\frac{3}{4}$ inch plate throughout. The sectional area of the rib at the centre is :—

	Without deducting Rivets.	Deducting Rivets.
Top flange	63·2	51·0
Bottom flange . . .	63·2	51·0
Web	40·5	40·5
Total square inches .	166·9	142·5

The sectional area of the rib at the springing of the arch is :—

	Without deducting Rivets.	Deducting Rivets.
Top flange	36·2	28·25
Bottom flange . . .	36·2	28·25
Web	30·0	30·00
Total square inches .	102·4	86·50

The spandrils are of wrought iron, except at the junction between the rib and the horizontal girder, where a small gusset piece of cast iron is introduced. The horizontal girder, which is 4 feet 6 inches deep with flanges 1 foot 6 inches wide, is continuous throughout, the whole bridge being riveted up for a length of 913 feet. It is firmly connected with the cast-iron standards at the piers, and at the abutments, in order to obtain the full advantage of continuity for the land spans, and is anchored by a plate running from the top flange right down to the cast-iron skewback. The flanges vary in thickness from 3 inches to $\frac{1}{2}$ an inch, and the web from $\frac{3}{4}$ inch to $\frac{1}{2}$ inch. The area of the horizontal girder in the weakest place is 63·4 square inches, or 50·8 square inches after deducting rivets. The main ribs are strongly braced by transverse girders, 3 feet 4 inches deep, of which there are eight to each rib (Fig. 18), and by vertical diagonal bracing from these girders to special cross-girders inserted for the purpose. To stiffen the whole structure the four centre ribs are cross-braced horizontally, by means of bars 4 inches by $\frac{5}{8}$ inch. The cross-girders and the rail-bearers are rolled beams of the Butterley Company's manufacture, the former 12 inches deep, $6\frac{1}{4}$ inches wide in the flanges, and placed 6 feet apart from centre to centre, and the latter 9 inches deep, $5\frac{1}{2}$ inches wide in the flanges, and firmly riveted to the cross-girders, forming a continuous bearing under each rail.

The passenger platforms (Plate 3, Fig. 3) are carried by cross-girders of the first-named section, in order that they may at any future time be available for additional lines of rails. The timber planking consists of baulks 12 inches by 10 inches, laid upon the rail-bearers, and secured by hook-bolts, with 3-inch planks in the intermediate spaces, except over the Grosvenor Road land-span, where a double platform with felt and sawdust is used, to meet the requirements of the Board of Works. The rails over the bridge are of steel, weighing 72 lbs. to the yard; they are flat-bottomed, and are firmly secured to the iron bearers at the joints by hook-bolts. The parapet of the existing bridge was removed from one side, and refixed with slight alterations to form the parapet of the new work. Full details of the construction of this bridge are shown in Plates 3 and 4.

The calculations of the strains, from which the superstructure was designed, leads to the conclusion that whilst cast iron is the best material for arched bridges of single spans, similar bridges of several spans, having piers whose perfect stability under horizontal stress could not be relied on, are under certain circumstances exposed to tensile strains, which render the use of wrought iron most desirable. The bridge was severely tested on several occasions by Major Rich, R.E., on behalf of the Board of Trade. Each rib, where practicable, with the exception of those adjoining

the original bridge, was tested with eight of the heaviest class of locomotives and tenders, weighing 360 tons, or thereabouts, which were allowed to stand on, and also to run over at speed; and the whole structure was then tested with twelve locomotives and tenders, weighing 530 tons, or thereabouts. The ribs deflected most uniformly, when fully loaded, to the extent of $\frac{7}{8}$ inch in the centre; the corresponding ribs in the adjacent spans at the same time showing a rise of $\frac{1}{8}$ inch in the centre. The girders over the land-spans, when fully loaded, showed a deflection in the centre of $\frac{1}{2}$ inch. The cross-girders, when a pair of driving-wheels rested exactly upon them, showed a deflection in the centre of $\frac{3}{8}$ inch. The permanent set in each case was scarcely appreciable. Careful observations have been made for nine months as to the effect of changes of temperature upon the structure. This effect is limited to a rise and fall of the crown of the arches amounting to a maximum of $1\frac{1}{2}$ inch, and a movement at the free ends of the land arch girders of $\frac{11}{16}$ inch.

The whole of the ironwork was supplied and fixed by Messrs. Ormerod and Grierson, of Manchester, the sub-contractors. The plates were all punched and the joints planed to templet at Manchester, and the ribs were built in their places, great care being taken to ensure accurate fitting in every part. The rivets generally used are $\frac{7}{8}$ inch in diameter, with 3 inches pitch. The total weight of wrought iron in one complete arched rib with spandrils and horizontal girder is 65 tons.

The chief materials used were :—

Timber in cofferdams and stages	286,000	cubic feet.
Bolts and spikes in ditto	220	tons.
Excavation	20,350	cubic yards.
Concrete in cement	4,950	,,
Concrete in lime	3,300	,,
Brickwork in cement	11,100	,,
Brickwork in lime	2,700	,,
Portland roach stone	39,900	cubic feet.
Bramley Fall stone	52,300	,,

	Tons.
Cast iron in permanent cylinders	461
,, in skewbacks and piers	386
,, in parapet (new)	38
Total cast iron	885

	Tons.
Wrought iron in ribs, cross girders, and bracing girders.	3,523
,, in bolts and nuts	18
Total wrought iron	3,541

The number of rivets used was 800,000. The total cost of the bridge has been £245,000, which is equal to about £2 13s. per

superficial foot of space covered, or about £38 per lineal foot of single line. The first stone of the new bridge was laid on the 22nd of February, 1865, and the first locomotive passed over in seventeen months from that date—on the 1st of August, 1866, when the bridge was tested by Major Rich.

High-Level Line of the London, Brighton, and South Coast Railway Company.

The West End and Crystal Palace Railway, between the Clapham Junction and the Thames, was constructed with a ruling gradient of 1 in ·55, and a curve of 13 chains radius, in order to pass under the London and South Western Railway. As these were found to interfere with the safe and expeditious working of the traffic brought upon the line when the Victoria Station became the West End terminus of the London, Brighton, and South Coast Railway Company, it was determined to construct a high-level line passing over the South Western Railway, and having ruling gradients of 1 in 120, and curves in no case of less than 22 chains radius, and to lay down three lines of way thereon—one for the express 'up,' one for the local 'up,' and one for the mixed down traffic. This line is $1\frac{1}{4}$ mile in length, and consists mainly of a viaduct of brickwork 35 feet 8 inches wide between the parapets, and varying from 15 feet to 40 feet in height to the rail level. The piers of this viaduct are carried down by means of cement concrete to a hard gravel substratum, except in one or two cases, where pile foundations were found to be necessary. The concrete is brought up to within 1 foot 6 inches of the natural surface, and the brickwork of the piers is then commenced. These, when not more than 8 feet high, are 3 feet $4\frac{1}{2}$ inches in thickness, increasing by an offset or plinth of $2\frac{1}{4}$ inches all round at every additional 8 feet. Each pier has a 'jack' arch in it of 6 feet span. The arches, which are built of gault bricks set in cement, are generally 30 feet span elliptical, with 10 feet rise, and show four rings on the face, but are increased where the load comes on to five rings. There are spandril walls of brick over each pier, the intervening spaces being filled with lime concrete, and the whole surface thoroughly asphalted to a thickness of 1 inch. Pipes are carried down each pier to a cesspool under the jack arch connected with a main drain. The plinths and copings are of blue Staffordshire bricks.

A branch line from the Wandsworth Road, three-quarters of a mile long, and forming a connection with the South London system, joins the high-level line, and is constructed for two lines of way. This branch is also on the high level passing over the London and South Western Railway, and is carried on a viaduct 24 ft. 8 in.

wide between the parapets, and averaging 30 feet in height to the rail level, of similar construction to that just described.

The bridges on these lines are of a heavy character, comprising

18	spans, wrought iron, from	. . .	26 ft. to 150 ft.
3	spans, cast iron, from	. . .	60 ft. to 70 ft.
9	spans, brick in cement	. . .	30 ft. to 57 ft.

The two bridges, however, which are chiefly deserving of notice, are those for carrying the high-level line over the London and South Western Railway (Plate 5), and over the West London Extension—London, Chatham, and Dover, and Brighton low-level lines at Longhedge. The former bridge has a central span of 149 feet, and two side spans of 47 feet each, and crosses the London and South Western Railway at an angle of 51°. It is constructed to carry three lines of way, and has two main girders of lattice construction, continuous throughout, resting at each end of the central span on cast-iron columns 3 feet 6 inches diameter, and 14 feet 6 inches high, and anchored down at the ends into the brickwork of the abutments, by means of rolled links, passing through stones, 4 feet by 4 feet by 1 foot 6 inches, placed a few feet above the ground level, and secured by cast-iron anchors. The ends of the girders are left free to move horizontally, the usual rollers being provided. The main girders are 10 feet deep from centre to centre of pins; the top flange is 3 feet wide, and is composed in the centre of the large span of

2	horizontal plates	. . .	$\frac{7}{16}$ in. and $\frac{3}{8}$ in. respectively.
5	vertical plates	. . . .	$\frac{1}{2}$ in. by 1 ft. 8 in.
2	angle irons	. . . .	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{1}{2}$ in.
2	,,	. . . .	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{3}{8}$ in.
2	,,	. . . .	$2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{3}{8}$ in.

The bottom flange is 1 foot 11 inches wide, and is composed in the centre of the large span of

3	horizontal plates	. . .	$\frac{7}{16}$ in.
5	vertical plates	. . . .	$\frac{1}{2}$ in. by 1 ft. 8 in.
2	angle irons	. . . .	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{1}{2}$ in.
2	,,	. . . .	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{3}{8}$ in.
2	,,	. . . .	$2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{3}{8}$ in.

The bottom flange is increased by $\frac{5}{8}$ inch in thickness over the columns. The struts, which are placed 5 feet $11\frac{1}{2}$ inches apart from centre to centre, consist of two plates 1 foot wide, varying from $\frac{1}{4}$ inch thick at the centre of the span to $\frac{5}{8}$ inch over the columns. These plates are stiffened with two angle irons, each $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{3}{8}$ inch. The struts contain a middle piece composed of two T irons 5 inches by $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch, and two plates 5 inches by $\frac{3}{8}$ inch, so that the pins have a bearing in three places. The struts are braced together with T irons 5 inches by $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch. The tension bars, which are of Howard and Ravenhill's rolled

links, are swelled out round the pins, so as to give 10 per cent. more sectional area than in the body of the bar, the diameter of the pin being, in each case, as nearly as possible, two-thirds of the width of the bar in the narrowest part. The bars, of which there are two to each bay near the centre of the bridge, and four to each bay elsewhere, vary from 6 inches by $\frac{1}{2}$ inch at the centre to 9 inches by 1 inch at the columns. The pins vary in diameter from $3\frac{3}{4}$ inches to $6\frac{1}{4}$ inches. The cross-girders are 40 feet 11 inches long and 2 feet 3 inches deep, 1 foot 7 inches wide in the flanges, and are placed as nearly 6 feet apart from centre to centre as possible. They are of ordinary plate-girder construction, and are suspended to the bottom flanges of the main girders by plates and angle irons. The rail-bearers are rolled beams manufactured by the Butterley Company. The whole bridge is stiffened horizontally by a system of cross bracing. The centre span of this bridge over the London and South Western Railway was erected without the use of scaffolding, by putting together the bottom flange and lifting it into its place, supporting it by temporary truss-rods, and then erecting the remainder of the girder upon it, the tension bars being inserted from either end till they met in the middle.[1]

The adjoining bridge, of 120 feet span, is of similar construction, but being only of one span, is not held down at the ends. The main girders, weighing 106 tons each, were built on the adjoining viaduct, and, when put together complete, were each rolled over into their places during the night, an operation occupying but four hours.[2]

The cast-iron bridges are composed of arched ribs, varying in span from 60 feet to 70 feet, and having a rise of 7 feet. These ribs are placed between the rails and under the parapets, and are 2 feet 6 inches deep, 1 foot 4 inches wide in the flanges, and are each cast in two segments.[3] (Plate 6, Figs. 3, 4, 5, 6, and 7). The skewbacks, spandrils, and parapets are of cast iron, the outer spandrils being filled with ornamental scrollwork. The cross-girders and rail-bearers are of Butterley rolled beams, of the same section as those for the Thames bridge. These beams are used wherever practicable throughout, as they are found to be considerably stronger than plate-girders of equal weight.

The brick arches, which vary in span from 30 feet to 57 feet, are generally segmental, constructed of gault bricks in cement, and faced with red bricks. They have a rise of 10 feet, and show five

[1] This bridge was tested with nine locomotives and tenders, weighing 430 tons. The deflection of the main girders in the centre was $1\frac{1}{2}$ inch, including a permanent set of $\frac{1}{4}$ of an inch.

[2] The deflection of the main girders under a test load of 430 tons was $\frac{15}{16}$ of an inch, including a permanent set of $\frac{3}{16}$ of an inch.

[3] The deflection of these ribs, when fully loaded, was $\frac{3}{8}$ of an inch, with a very slight permanent set.

rings on the face, being thickened, where the load comes on, to six or seven rings, according to the span. Several of these bridges are very much on the skew.

A spacious and convenient station has been erected at the junction between the high-level main line and the South London branch, and the original Battersea Park Station has been entirely rebuilt. At this point a foot-bridge of lattice-work girders, having five spans of 65 feet each, carrying a platform 10 feet wide, supported upon cast-iron columns, has been erected to connect the station and pier with Battersea Park.

Diversion and Raising of the West End and Crystal Palace and West London Extension Railways.

This was one of the first alterations carried out in the district, and was necessary in order to provide separate lines for the Great Western traffic, and also to raise the lines to a height of 18 feet, so as to allow a new carriage-road to pass under them, and to bring them to the proper level for a junction-line to the south. As the whole main line and Crystal Palace traffic of the Brighton Company, as well as the Great Western traffic, was passing over these lines, this operation was one of some difficulty; but by diverting and raising one-half of the lines at a time, and slewing the roads at either end in the night, it was carried out without delay or accident.

High-Level Line of the London, Chatham, and Dover Railway.

This line, which is constructed for three lines of way, is 1 mile in length, and is carried chiefly on a viaduct, similar to those already described, passing over the London and South Western Railway, and running from the southern end of the Victoria Bridge to the railways of the Company at Wandsworth Road. It has ruling gradients of 1 in 120, and minimum curves of 20 chains' radius. The bridges on this length are heavy, comprising fourteen spans of wrought iron, from 25 feet to 98 feet; but they do not call for special remark, with the exception of the bridge over the York Road. (Plate 6, Figs. 8, 9, and 10). The main girders are of lattice construction, 7 feet 2 inches deep from centre to centre of pins, and 112 feet in length, continuous throughout, the bridge being divided into two unequal spans of 72 feet and 43 feet, and supported by cast-iron fluted columns 2 feet 6 inches diameter and 13 feet in height. The girders are divided into bays of 7 feet 2 inches each, the struts and ties being inclined at an angle of 45°, but over the columns vertical struts are inserted.

The top flange of the main girders is 2 feet wide, and in the centre of the larger span is composed of:—

6 horizontal plates, altogether	2 ft. × 3 in.
2 vertical plates, each	1 ft. × $\frac{3}{8}$ in.
2 angle irons, each	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{1}{2}$ in.

The bottom flange is 1 foot 4 inches wide, and in the centre is composed of:—

9 horizontal plates, altogether	1 ft. 4 in. × $3\frac{1}{2}$ in.
2 vertical plates, each	1 ft. × $\frac{3}{8}$ in.
2 angle irons, each	$3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{1}{2}$ in.

The struts and ties alike consist of plain bars varying from 6 inches by $\frac{3}{8}$ inch to 8 inches by $\frac{9}{16}$ inch, and in sets of two or four, according to position. The struts are stiffened by angle iron lattice-work, and the ties are thickened round the holes for the pins by plates riveted on: the pins vary in diameter from $2\frac{3}{4}$ inches to $3\frac{3}{4}$ inches. The cross-girders are 3 feet deep, and are suspended from the bottom flange of the main girders. They, as well as the rail-bearers and horizontal bracing, are similar to those for the bridge over the South Western Railway already described. The ends of the cross-girders are hidden by cast-iron filling-pieces, and light ornaments are attached at the points of intersection and junction of the struts and ties. Near this bridge a station has been erected for the Battersea Park traffic.

Longhedge Junction Railway.

This branch is a double line, 32 chains in length, and is carried on a brick viaduct, similar to those before described, through and over the Chatham and Dover workshop-sidings, and forms one of three railways which cross each other at different levels at this point. This branch, though not presenting any features of special interest, is of much importance, forming, as it does, the link by which the traffic from the north of London, Kensington, and the south-western district passes to the lines south of London and the City.

Connecting Link to Clapham Junction.

This is a double line $1\frac{1}{4}$ mile in length, which, leaving the branch last described, and running for some distance on embankment side by side with the West London Extension Railway, passes under the London, Brighton, and London and South Western Railways, and then rising by a gradient of 1 in 54 on a curve of 16 chains' radius to the level of the London and South Western Railway, runs into Clapham Junction Station. For a length of 450 feet this line is on a viaduct 24 feet 8 inches wide between the

parapets, and of the average height of 20 feet. This viaduct is similar to those before described, except that the arches are semi-circular, and of 25-feet span only. The bridge under the railways is constructed to carry eleven lines of way over it. In order to construct this bridge without interference with the traffic, a closely-boarded heading was first driven for the abutment, which was carried forward only in short lengths at a time. This being done, baulks were laid under the rails and the main and cross-girders got into their places, the old embankment not being removed until after the completion of the bridge.

Low-Level Lines from Victoria Bridge.

These two single lines of mixed gauge, which leave the high-level line one on each side immediately south of the Thames, are each 24 chains in length, one being chiefly on viaduct and the other on embankment. They fall from the high to the low level with a gradient of 1 in 60, and are the means of connecting the low-level system and the West London Extension Railway with the Victoria Station. These two lines carried for a time the whole of the Chatham and Dover and the Great Western traffic, and it is worthy of remark that the whole of the lines formerly leading into the London, Chatham, and Dover portion of the station were cut off and new lines substituted during six hours in the early morning of December 20th, 1866.

General.

The permanent way on these lines does not call for special remark, being of the description used on the main lines of the respective companies, except that the London, Chatham, and Dover high-level line is laid with steel rails weighing 72 lbs. to the yard, manufactured by Sir John Brown and Co., and that a portion of the Brighton line is also laid with steel rails.

This system of railways, comprising a length equal to 9 miles of double line, of which 5 miles are on viaduct, has cost for works only, including the bridge over the Thames, the sum of £910,000. The high-level line of the Brighton Company, which is entirely on viaduct, has cost, including permanent way, stations, and signals, and the numerous heavy bridges, the sum of £45 per lineal yard of double line: 60,000,000 of bricks, 7,700 tons of wrought iron, and 1,600 tons of cast iron, have been used.

The works of the London, Chatham, and Dover Company have been carried out partly by Messrs. Peto, Betts, and Crampton, and partly by Messrs. Lucas Brothers; the general works of the London, Brighton, and South Coast Company by Messrs. William

and John Pickering, and the ironwork by Mr. James Heywood, Jun., of Derby; the works of the London and South Western Company by Messrs. Peto, Betts, and Crampton, who were represented throughout by Mr. Curry. The whole have been executed from the designs and under the superintendence of Sir Charles Fox, M. Inst. C.E., and the Author, Mr. Edmund Wragge being the Resident Engineer. The works have taken three years to complete.

The Author trusts that this record of works, all forming parts of the same design, and which have, by the separation of traffic and the improvement of gradients and curves, already effected a marked improvement in the working of the traffic, may be found interesting and useful. He has been unable, within the limits of this communication, to enter into any great amount of detail, but has endeavoured to describe the salient points of the railway system of a district which he believes has few equals, as regards the immense and daily increasing traffic which has called for the construction of the works described.

This Paper is illustrated by a series of diagrams, from which Plates 3, 4, 5, and 6 have been compiled.

APPENDIX.

WIDENING OF VICTORIA BRIDGE, PIMLICO.

PARTICULARS OF LOADING.

	tons.	cwt.
Weight of metal in one rib	65	0
,, ,, in rolled beams	20	10
,, ,, in bracing girders, brackets, wind ties, &c.	13	10
Total ironwork . tons	99	0
Weight of timber platform	25	0
,, rails and bolts	7	0
Total dead load . tons	131	0

Distance apart from centre to centre of piers, 187 feet 4 inches.

Dead load equal to $\frac{3}{4}$ ton per foot run per rib.
Live load taken as $1\frac{1}{4}$,, ,, ,,

Total load . . 2 tons ,, ,,

Span being taken as 175 feet, load as 350 tons.
Rise of arch 17 feet 6 inches.
Compressive strain on rib at centre of loaded span = 419 tons.
,, ,, at springing ,, = 460 tons.

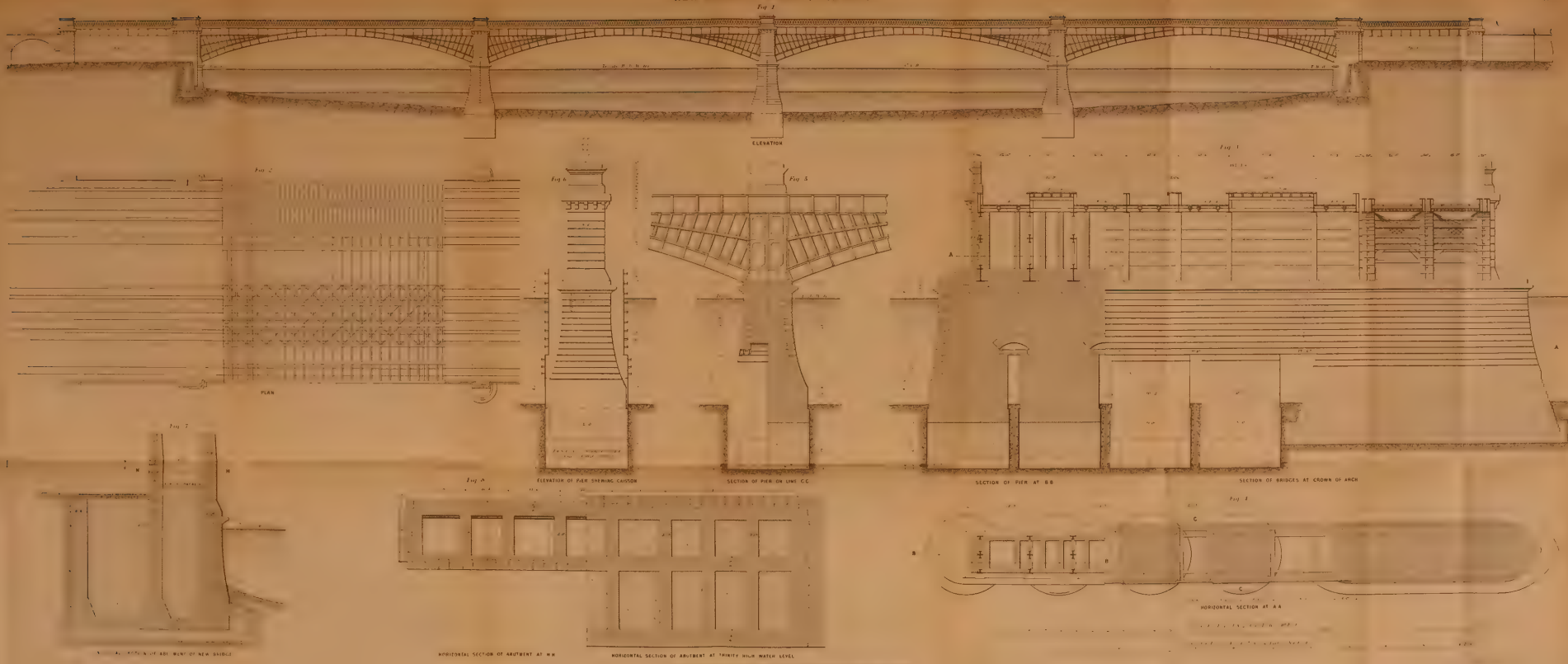
Mr. Wilson said, he should like to be furnished with some further details of the testing of the New Victoria Bridge. It was stated that the load was 360 tons, but it did not appear how much of the bridge was covered lineally by that weight.

Mr. Fox said the load just covered one span.

Mr. Wilson had not offered any theoretical opinions, nor instituted any comparisons in his Paper, although the extraordinary instance of an entire bridge being built at different periods by two engineers upon totally different principles, when the circumstances to be dealt with were the same—the same loads to be carried—the same spans and rise of arches, and the same waterway—was, he thought, a matter for careful consideration.

Mr. C. Douglas Fox observed that the New Victoria Bridge afforded an example of a thoroughly continuous pier, above low-water mark, founded upon cylinders. In designing the bridge, it was necessary to provide against the difficulty, imposed by the terms of the Act of Parliament, of connecting the new work with the then existing Victoria Bridge; and that circumstance materially affected the whole character of the design. It was a matter of interest, that a length of 913 feet of horizontal girder was riveted up over each pier from end to end. This was completed at a temperature of about 60°, the operation being postponed till that temperature was obtained. The strains on this bridge were shown in Fig. 11, Plate 6. He might state that the ribs and horizontal girder were considered together as continuous girders of varying depth, or as two cantilevers projecting from each pier, and one from each abutment, with an intermediate horizontal girder in each span, the cantilevers being each 51 feet 6 inches, and the horizontal girder 75 feet in length. The question of the stability of the piers was in this case not taken into account. It would be seen that if one span were entirely loaded, and the next span unloaded, there would be an upward strain in the centre of the unloaded span. That strain, which was 30 tons, was consequent upon the horizontal thrust of 149 tons at the springing, and would put a tensile strain upon the horizontal girder and rib, which were blended at that point, of 4·3 tons per square inch of section. If the span at the other end of the unloaded span could also be loaded it would increase that strain to 8·6 tons: but it was hardly within the bounds of possibility that, for example, spans Nos. 2 and 4 should be fully loaded for the full width of the bridge, No. 3 being at the same time unloaded. He would mention again the results of the tests. When No. 2 span was loaded both No. 3 and No. 1 each rose up $\frac{1}{8}$ inch in the centre: and the effect of the stiff cross and vertical bracing, and of the way in which the cross girders were connected with the main ribs, was such that, when two of the ribs were loaded fully, the adjacent

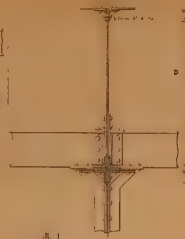
NEW VICTORIA BRIDGE, PIMLICO.

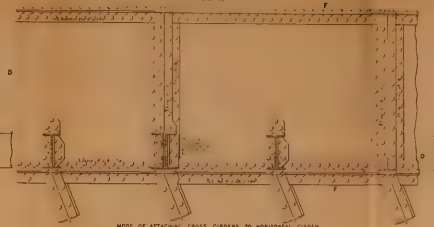


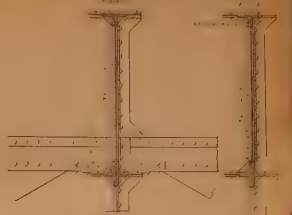
NEW VICTORIA BRIDGE, PIMLICO.

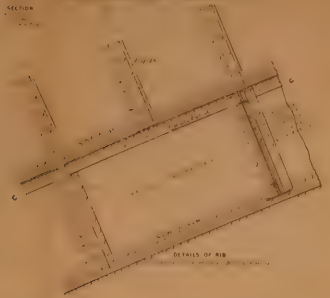
ELEVATION OF HALF RIB

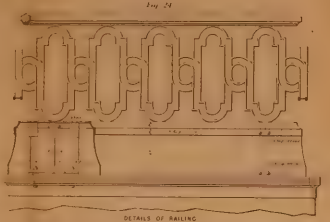
DETAILS OF PLATFORM.

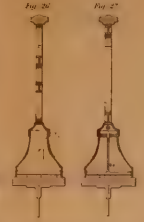



MODE OF ATTACHING CROSS GIRDERS TO HORIZONTAL GIRDER

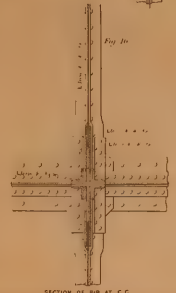

SECT. ON A.B. C.D.

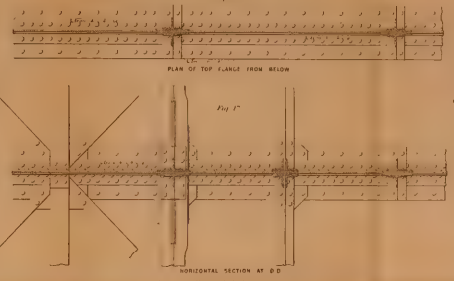

DETAILS OF RIB

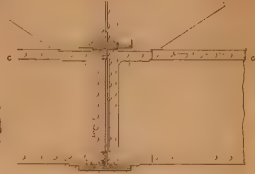

DETAILS OF RAILING



DETAILS OF WROUGHT IRON CYLINDERS.

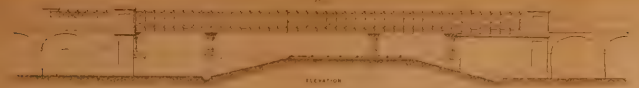

SECTION OF RIB AT C.C.


HORIZONTAL SECTION AT D.D.

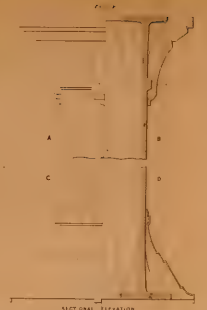

SECTION AT E.E.

NEW RAILWAYS AT BATTERSEA.

BRIDGE OVER THE LONDON & SOUTH WESTERN RAILWAY



ELEVATION



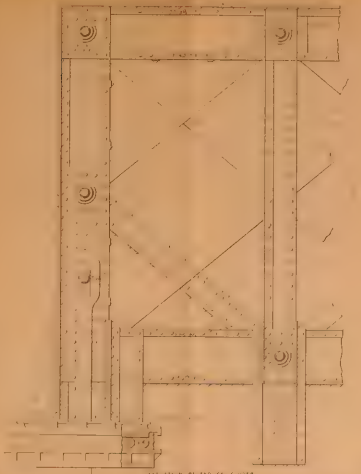
SECTIONAL ELEVATION

HALF PLAN ON TOP

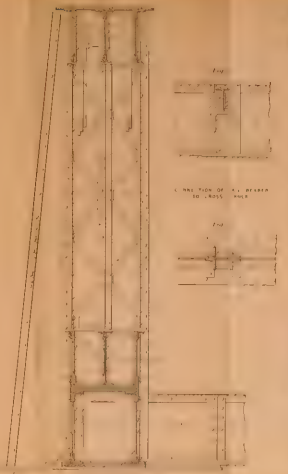
SECTION AT A B LOOKING TOWARDS

SECTION AT C D

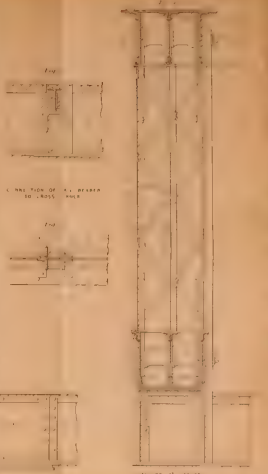
HALF ELEVATION OF GIRDER



ELEVATION OF END OF GIRDER



ELEVATION

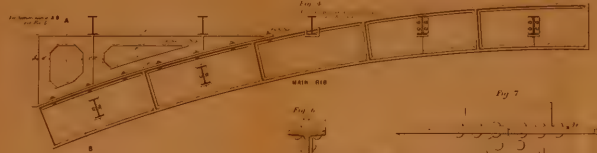


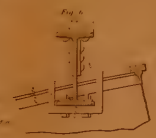
SECTION AT A B

L.B.S.W.R.
L.C.&D.R.
L.B.&S.C.R.
N.L.
RAILWAYS IN BATTERSEA
1863.

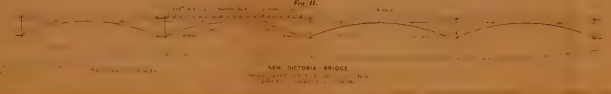
RAILWAYS IN BATTERSEA
1863

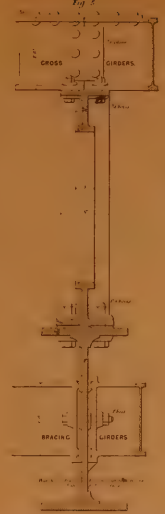
BRIDGE OVER PRINCE OF WALES ROAD L.B.&S.C.R.


MAIN RIB

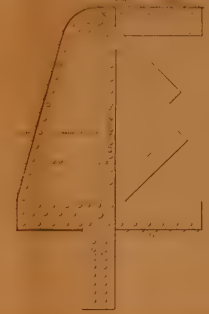


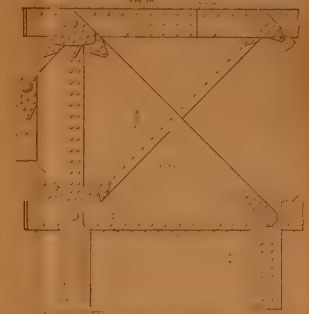
CROSS GIRDERS.


NEW VICTORIA BRIDGE


CROSS GIRDERS.
BRACING
GIRDERS

BRIDGE OVER YORK ROAD, L.C.&D.R.





rib showed a deflection of $\frac{1}{8}$ inch. He made out, on the assumption that the variation of the temperature was 50° on each side of 60°, that the strain caused by expansion and contraction was equal to 4 tons on each inch: for iron, within the elastic limits, was compressed or extended ·000084 of its length by each ton of pressure or strain respectively upon a sectional inch; and by a variation of temperature of 50°, it was expanded or contracted ·000349 of its length, or rather more than the amount produced by 4 tons to the inch. A useful question for discussion, not raised in the description of these bridges, was the comparative merits of cast iron and wrought iron for an arched bridge of several spans, when the piers were not relied upon as perfectly stable. That would have no bearing upon the comparison of these two bridges, as they were both of wrought iron. But it was a matter which had been fully gone into by Sir Charles Fox himself, in which they had the assistance of Mr. Ordish, who superintended the preparation of the drawings for the iron-work details. They came to the conclusion that it was essential, where there were several spans of this kind, without perfectly stable piers, to adopt wrought iron to meet the tensile strain of which he had spoken. He would remark, with regard to the bridge over the South Western Railway, that when the centre span was loaded there would be a strain on each of the anchors of 68 tons, and the total weight on each column would then be a little over 400 tons.

The operation of rolling the girders of the bridge of 120-feet span into place was a matter of some difficulty, because the bridge crossed six lines of railway with a constant traffic, excepting during the four hours of the morning from half-past twelve to half-past four. The chief difficulty was to steady the girder sideways during the operation of rolling, the width of the bottom flange upon which it had to be supported being 2 feet and the depth of the girder 11 feet 6 inches. The first operation was the erection of the main girder on the abutment; it was trussed with temporary rods, and wooden distance-pieces were inserted between some of the ties, to meet the contingency of their having to act temporarily as struts: and several of the cross girders were attached to the tail of the main girder, and weighted with rolled beams. The girder was then rolled over about one-third of its length. As soon as the traffic was stopped a temporary railway of 4 feet $8\frac{1}{2}$ inches gauge was laid as expeditiously as possible, upon which a trolly, consisting of two wagons firmly connected side by side, each wagon having four wheels 2 feet diameter, was run under the girder, which was then firmly attached to it. Stout balks of wooden packing were fixed underneath the trolly and between the axles to receive the weight in case of the fracture of an axle. Small wooden

projections with wedges and chain guys were used to steady the trolly sideways; and struts were carried from the trolly up to the top of the girder, men being stationed there to keep them constantly tight by means of wedges. This operation was completed with ease in four hours, the motive power consisting of two crabs, one on each abutment, and crowbars applied to the trolly wheels. If, instead of the solid cast-iron rollers which were used on the abutment, it had been possible to substitute another trolly at that end, the work could have been performed in much less time. All the arrangements were carried out by the contractor, Mr. James Haywood, Jun., of Derby.

With reference to the Victoria Bridge, he would venture to throw out the following questions:—

1st. Might the piers of such a bridge as this be taken as really stable or not?

2nd. If the piers were perfectly stable, was not the bridge resolved into several bridges of single spans; and if so, would not cast iron have been the best material to use?

3rd. If the piers were unstable, and the platform and dead load light—as was the case in this bridge—must not tensile strain produced by upward motion in the unloaded span be provided for; and would not that be best done by wrought iron?

4th. Did not riveting up the horizontal girder from end to end increase the strength of the structure?

It would be noticed that he qualified the 3rd question by stating that the platform and dead load were light: the headway was limited, and therefore the platform was comparatively light. But there were instances of bridges over the River Thames on which there was a great thickness of ballast and heavy cast-iron plates; and it was found that, under such circumstances, cast-iron ribs had been advantageously used; as was also the case in road bridges where the metalling was of considerable weight, and where the dead weight was far greater in proportion to the live load than in the present instance. The reason he thought wrought iron was in the present case rightly used was that it had to meet the tensile strain; but in cases where there were heavy platforms, or a large amount of ballast, the strains were much modified and cast iron would be applicable.

Mr. Callcott Reilly observed, that this was probably an unique opportunity for deriving useful lessons for the future, from a comparison of what purported to be two entirely different systems of construction of iron arches, which had been adopted to attain precisely similar objects, and under circumstances exactly the same, so far as regarded the superstructure.

As these were the only Papers on the subject of iron arches in the entire series of twenty-seven volumes of the Minutes of Proceedings of the Institution, with one immaterial exception, it was to be regretted that the Authors had not given more information, bearing upon the principles which had guided them in the design of these two bridges.

Mr. Wilson had said, that there was a radical difference in the principles of the two designs, and he seemed to invite discussion on that question: yet, in his Paper, as well as in that by Mr. Fox, all mention of principle was carefully avoided. If the Authors desired to raise a discussion upon the principles of design of iron arches, they should have given a full explanation of their own principles, and a complete *résumé* of the calculations upon which these designs had been founded. It was commonly said that comparisons were odious; but it would be impossible, while comparing these two systems of construction, to avoid indicating an opinion that one was better than the other. Therefore, he hoped the Author whose designs were depreciated in the comparison, would attribute any objections that might be made to the true motive, that of an honest search after correct principle.

Coming to details, and taking Mr. Fowler's design first, he saw little room for criticism, in the absence of the calculations to which he had referred. Both designers were quite right, in his opinion, in preferring wrought iron to cast iron as a material for the arches of a bridge of several spans, which had to carry a relatively heavy moving load, and whose intermediate piers had but small stability to resist the unbalanced horizontal pressure which was applied to them when one arch was loaded, and one or more of the others unloaded, by the heavy moving load. The enlargement of span which resulted, sometimes produced tensile stresses upon the iron, as had been mentioned by Mr. Fox. It was that instability of pier which constituted the chief difficulty in the design of such arches as these, not specially because of mathematical intricacy in the analysis,—for that pervaded the whole subject,—but because experiments were wanting to establish general principles relative to the yielding of piers, under the action of unbalanced horizontal thrust. He would suggest, that engineers who had designed iron bridges of this kind, and who had the opportunity, should ascertain by actual measurement the enlargement of span due to the unbalanced thrust produced by heavy rolling loads, and should publish the results of those experiments, accompanied by a sufficient statement of the circumstances, so that in course of time a principle might possibly be evolved from a sufficient number of facts so obtained. In the absence of accurate data of the kind just referred to, Mr. Fowler had adopted a practical method, worthy of imitation, of equalising, to a certain extent, the varying stresses which resulted

partly from enlargement of span under the influence of the heavy moving load, partly from the deflection, and partly from the changes of temperature. He alluded to the hinging of the arched ribs at the piers, which prevented the occurrence of any bending moment at the springing, by confining to one point the intersection of the line of resistance with the surface of the skewback; that point then coinciding with the like intersection of the neutral curve with the same surface under all conditions of load—a circumstance which facilitated the work of investigation and computation; and also to the use of cotters, which could be tightened according to the judgment of the engineer. He should be glad if an explanation were given of the principle which had guided the use of the cotters, and of the amount of cottering-up required under given circumstances. He presumed the principle to be this: — By tightening up the cotters, an initial compression was caused upon the lower edge of the arched rib, in addition to that which previously existed, and a corresponding diminution of the previously existing compression on the upper edge. The effect of this was to raise the crown of the arch above its former position. Those initial stresses would be properly considered in proportioning the sections of the ribs; and as they were of opposite kinds to those produced by the deflection, and by the enlargement of span caused by the unbalanced thrust due to the moving load, and also by change of temperature under certain conditions, the action of those disturbing forces would diminish the inequality of these initial stresses, and perhaps, going beyond that, would produce unequal stresses of the opposite kinds to the initial stresses. It was, therefore, obvious that the inequality of stress, produced by the action of those disturbing forces, would be much diminished by the judicious use of this cottering system. For his own part, he thought the arches might be hinged at the curve as well as at the springing, as proposed by some French engineers; this would have the effect of annulling altogether the stress produced by change of temperature.

Turning now to the other bridge; he gathered from Mr. Fox's remarks, that the whole series of arches, together with the horizontal girder connected with them, had been considered as one continuous beam. In opposition to that view he would suggest, that there were two essential characteristics of a beam, whether continuous or not, which were both absent in this structure, and that, therefore, it could not be properly treated as a continuous beam. He alluded, first, to the necessity which existed in every beam, or any combination of pieces which acted as a beam in supporting a vertical load, that the lines of action of all the supporting forces should be vertical, or in mathematical language, that the horizontal components of the supporting forces should be null. In this design the supporting forces at the three intermediate

piers fulfilled that condition, but not so at the abutments. There the ribs rested upon oblique skewbacks, and there was obviously a horizontal component, at those two points of support, equal to the horizontal thrust at the crown, and that circumstance alone rendered the structure amenable to the laws which governed the strength of iron arches, as distinguished from beams.

The other essential characteristic of a beam, which was absent in this system, was that a vertical web was necessary, composed either of solid plate or triangular bracing, sufficient to convey the shearing forces, from the points of application of the loading forces, to the points of support at the piers. In this system there was no such web, there were only the radiating bars which occupied the spandrils, and which merely acted as posts in transmitting the load from the points of application on the roadway to the back of the arch; and, therefore, the shearing forces could only be transmitted to the supports through the arched rib, producing compression upon it.

Consequently, this system was really a system of arches, and not of continuous beams, and its principle was analogous to that of a suspension bridge, but inverted, stiffened by a horizontal girder, which acted much in the same way as was described in the discussion upon the Clifton Suspension Bridge, and upon Suspension Bridges of Great Span, last session[1]: and it might be treated by a similar method. In fact, that was the fundamental principle of all correct methods of calculation, applicable to metallic arches without braced spandrils.

Neither of the Authors had given any detailed weights, and, therefore, no conclusion could be arrived at as to the economy of material in these structures. The gross quantities of materials used in the Victoria Bridge had been given, but it was not stated how the weights were distributed. It would be useful to know how much iron was placed in the important members of each bridge, as well as the gross weight. It had, however, been incidentally mentioned that one of the bridges over the London and South Western Railway had two main girders of 120-feet span, and weighing 106 tons each, which were officially tested by a distributed moving load of 430 tons on the bridge. This pair of girders might, therefore, be assumed to have been designed to carry that moving load, and they weighed 212 tons. If that were so, he thought it an extravagant weight. He believed that bowstring girders might be made to carry the same moving load with considerably less than half that weight, and to satisfy every scientific and practical condition of success.

Mr. GREGORY—Vice-President—said, perhaps the Authors would

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 265, *et seq.*

be kind enough to supplement their respective Papers by the calculations and detailed weights to which Mr. Callcott Reilly had alluded.[1]

Mr. G. H. Phipps said, he had always taken much interest in the subject of iron arches of large span, but especially so from the time of the rebuilding of Sunderland Bridge, on which he had been engaged under the late Mr. Robert Stephenson. He had made a design for a suspended tubular bridge on the site of the Victoria Bridge, which design he had alluded to in the discussion on the Clifton Bridge.[2] The piers were in line with those of the Chelsea Suspension Bridge, and the central span was 400 feet. This design was prepared at the time when the Victoria Station and Pimlico Railway was before Parliament, as he thought it might serve as an alternative, in case the waterway to be afforded by the Victoria Bridge was objected to.

Having had, at an early period, an opportunity of examining the particulars of the various strains on the Victoria Bridge, he had availed himself of them in his calculations.

There was no question that the area of the base of the foundations of these two bridges was amply sufficient for the dead weight to be carried, which amounted, in the Victoria Bridge, to rather less than 2 tons to the square foot, where a weight of about 8 tons per square foot was borne by the foundations of the Charing Cross Bridge.

Assuming, then, that it was decided to build an arched bridge in the present situation, and drawing no comparison at the moment between it and a girder bridge, he thought it was impossible to have designed better or more substantial piers and abutments than those of the Victoria Bridge. When piers were constructed for an arch bridge, it was not only necessary for them to have sufficient bearing surface upon the foundation, which would be all that was necessary for a girder bridge, but they must also possess sufficient lateral stability to meet the unbalanced thrust of neighbouring arches when unequally loaded. With a view to ascertain this, he had calculated the direction of the resultant for two cases. In the first, where one arch was taken as entirely unloaded, and the half of the adjoining arch most remote from it was loaded with 1 ton to the foot lineal on each line of way. The resultant cut the pier, at the level of the bottom of the river, at about 5 feet 6 inches from the centre line. In the other case, where one arch was supposed fully loaded, whilst those adjoining were unloaded, the resultant cut the pier, at the above level, at about 6 feet 6 inches from the centre line, being $2\frac{1}{2}$ feet from the outside of the masonry. He

[1] This information will be found in part in the Appendix to each Paper.—Sec. Inst. C.E.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi, p. 302.

had calculated the stability at the level of the bottom of the river rather than lower down, because it increased so much at lower levels as to be clearly more than sufficient. The effect of the distance to which the resultant diverged from the axis of the pier was to throw an increased strain on the outer portion of the masonry. If the perpendicular pressure per square foot were taken at $2\frac{1}{2}$ tons, and if it were increased from the above cause to 8 tons, still, although that pressure was considerably within the limits which the material would bear, the divergence of the line of pressure from the axis of the pier should give rise to a slight curvature, an effect which, it was believed, had been observed in practice.

He would now refer to a few of the leading peculiarities of the superstructure of the Victoria Bridge. One of these was the circular abutting ends of the arched ribs; this was not a novelty, as it had been adopted in an aqueduct bridge across the River Calder; but still it might be desirable to inquire whether it possessed any advantages. The next point was the manner of filling in the spandrils. In most of the older bridges the space between the extrados of the arch and the roadway bearer was filled in with vertical pillars; whereas in the present instance they radiated to the centre of the arch. The third remark had reference to the horizontal beam over the top of the arch, and the peculiar expansion joint where it rested upon the pier. He thought the circular abutting joint at the springing of the arched ribs was not desirable for the following reasons:—When an arch was loaded irregularly, the curve of equilibrium no longer ran along the neutral axis of the material, but began at some point in the skewback, and diverging from the neutral axis to a degree commensurate with the irregularity of loading, often reached nearly to the extrados or intrados of the arch. Now, if the circular abutting joint were used, the above curve would be obliged to start from the abutment at the centre of the depth of the arch; whereas, if the arch started from a flat skewback, the curve of equilibrium might commence at some point either above or below the central line: it would not travel so widely away from the centre line, nor distress the material so much. There appeared to be a similarity of action in the case of an arch with flat ends, to pillars similarly formed, which, as all engineers knew, were much stronger than pillars with rounded ends. If the end of the arch, when flat, had a tendency to nip more at one point than another, the angle so pressing on the skewback had a tendency to correct the disturbance of the arch itself; and for these reasons he was inclined to prefer a flat skewback.

He did not think the radiating direction of the spandril-filling so good as the system with vertical pillars. In an arch in equilibrium, the load, at each equal division measured horizontally, came down upon the back of the arch vertically, and engaging itself with the

forces already resident in the arch, produced a resultant strain passing along the axis; whereas, if the load were transferred to the arch through the medium of radiating pillars, the effect would be to throw more than its proper share of pressure upon the arch, in proportion to the inclination of the pillars towards the springing. It was true that in the design now under discussion, the inclination of the pillars was but small; still he thought, as a matter of principle, it was right to mention it.

It had been the fashion in recent bridges to make the horizontal girders above the arch very strong and deep, but he thought this member might safely be made lighter. In most of the older arched bridges the horizontal roadway bearers were made very light and shallow, and the supporting pillars vertical; and it was worthy of inquiry whether, if, in the present design, a portion of the metal were taken out of the girder, and transferred to the arch itself, greater stiffness would not be secured. No doubt these strong horizontal girders assisted to diminish the distortion of the arch, in a similar manner to that in which they corrected the disturbance of the curve in suspension bridges, but the degree in which they so acted was much greater in the suspension than in the arch bridge, in consequence of the far larger disturbance of the curve in a suspension bridge of the same span and versed sine with an arch bridge, with similar variation of loading. In a suspension bridge, unequally loaded, the chain arranged itself in the curve of equilibrium due to the load, while in the arch, although the curve of equilibrium underwent an equal change of figure, the arch itself underwent scarcely any alteration, at least, none in comparison to the chain; and this small movement constituting all the deflection which the girders above the arch would have to undergo, the strain against them would be proportionately small, and their corrective influence slight.

He would briefly refer to the expansion joint in the horizontal girders, which was intended, in the language of the Paper, to keep up "the continuity of strain." If by this it were meant that the effect of the expansion joint would preserve the same amount of strain, into which the horizontal girder would be thrown by contraction and expansion, he scarcely thought this result would be effected: for the India-rubber washers would have to bear an equal pressure to that of the metal of the girders, from an expansion due to half the variation between the highest and lowest temperatures, which half, if taken at 30°, would equal 2 tons on the square inch, or from 90 tons to 100 tons on each girder. The end of each girder would also, if allowed freely to expand with the above temperature, move through a space of about $\frac{1}{4}$ inch, but the girder would be subject to no strain; and some smaller amount of motion could only be counted upon. If this were

taken at one half the above, or $\frac{1}{8}$ inch, the compression upon the iron would be only 1 ton on the square inch, or one half of what it would be were the girders attached immovably to the piers. His opinion that the piers probably underwent some slight deflection, in consequence of the departure of the line of pressure from the perpendicular, appeared to be borne out by the deflection of the arch under the load of 175 tons, or 1 ton per foot lineal of the arch. The deflection was stated to have been $\frac{7}{8}$ inch, but he considered this was double what it should have been, according to the data furnished; and he attributed the excess to the slight yielding of the piers. His conclusion, that the deflection was double what it should have been for an arch, was arrived at by computing the deflection of a girder 175 feet long and 17 feet 6 inches deep under a similar load, which he found to be about $\frac{7}{8}$ inch, and then assuming that the deflection of an arch should only be half as much. This followed from the fact that in the girder the deflection due to any element was as the compression or extension of that element taken into its distance from the point of support, and divided by the distance from the neutral axis, or half the depth of the girder. In the arch the calculation was the same, except that instead of dividing by half the depth, the whole depth had to be taken, giving, of course, one half the deflection only. It was, perhaps, worthy of inquiry whether a girder bridge might not have been constructed for less money, from the saving which might have been effected, under that system, in the piers and abutments and in their foundations.

With respect to the widening of the Victoria Bridge, the principal points for consideration appeared to be, the nature of the foundations, and the continuity of the horizontal girders above the arches, and the permanent bolting of them to the tops of the piers and abutments. Although cylinders of cast iron, sunk deep into the clay, formed an excellent foundation for supporting a vertical load, as in the case of a girder bridge, he thought they were not so well calculated to afford the requisite lateral stability for an arch bridge as solid piers. At or about the level of low water, the piers in both designs were of the same width, and at this level both were of the same class of material, but the stability of the piers of the widened portion was less than the others, in consequence of their resting only upon the base afforded by the four bearing cylinders, instead of bearing all along as in the original piers. This had the effect of reducing the area of the horizontal section at low-water level of 1,513 square feet by 396 feet, leaving 1,117 square feet as the total area; consequently the pressure per square foot of the brickwork was increased. There was also an evil connected with the apertures left between the cylinders, and between the last cylinder and the cutwater of the original bridge, as at high water

there was an upward pressure of water equal to 176 tons on each pier, which of course lessened the stability. Had there been any saving in expense there might have been some reason for adopting the cylinders, but as the expense per superficial foot of the completed bridges appeared to have been identical, he should have preferred the solid pier. On the question of the continuity of the vertical girders, and securing them to the piers and abutments, there was an observation in Mr. Fox's Paper which almost seemed to imply, that the piers were wanting in lateral stability, and that the continuity of the horizontal girders was employed to aid the piers in this respect. Now, as an engineer, he would certainly object to erect an arch bridge upon piers of insufficient width of base and weight, to ensure the resultant of the strains falling far enough within the base to secure the necessary stability. If the piers were not so erected, he thought the action of the continuous girders scarcely competent to give them the requisite support: for whether the whole length of the longitudinal beam were either expanded or contracted from its length at a mean temperature, the whole of the strain would be taken upon the abutments, leaving the piers in a perfectly neutral condition, and at liberty to move through a small space before the longitudinal beams came into action. This alternate motion, in opposite directions, might loosen the iron standards to which the beams were secured, and disturb the brickwork, particularly at the abutments, where, with a variation of 30° each way from the average, a strain of about 2 tons on the square inch, or about 100 tons on each girder, would be concentrated.

Mr. R. P. Brereton thought the two structures under consideration were as similar as could be, although the observations of the Authors of both Papers would lead to the belief that the Engineers were influenced by different ideas when they designed these bridges; at all events, both bridges had answered the purposes they were intended to fulfil. The first had already been in use for ten years; and any misgivings that might have arisen, from the fact that the employment of light boiler-plate arches, without some means of stiffening, was comparatively novel, must have long ago been dispelled. The Engineer by whom the widening of the bridge had been carried out, had probably been induced to preserve a similarity in the appearance of the two structures. There was a slight difference in the construction of the piers: in the original bridge large coffer-dams were used, and there was a good base to each pier; in the other the base was slighter, and the piers were built without the employment of coffer-dams. The only other difference was that in the first bridge each horizontal girder was connected over the piers by an expansion joint, in which, by the use of India-rubber rings, under the nuts of the junction bolts,

a certain amount of elasticity was obtained. The result of expansion and contraction, to the extent of about $\frac{2}{3}$ inch in length, due to a range of temperature of between 50° and 60°, which alone gave trouble in these matters, had produced a rising of the crown of $1\frac{1}{2}$ inch in each of the spans of the second bridge. As the whole top member was riveted together, it ought, theoretically, to have expanded considerably. But it turned out that the expansion recorded was due to the length only from the centres of the two end arches to the extreme ends of the girders; and the expansion, equal to $\frac{2}{3}$ inch to each intermediate arch, had disappeared; so that there would be no tension during high temperatures. He did not see the use of the upper member being very strong for the purpose of always resisting tension. There was no doubt that, when light iron bridges like this, weighing about a ton per foot run, or the same as the moving load, were irregularly loaded, they did not fall, and that something else was in operation than the mere arches. It could not be said that the piers did not tend to prevent such a result. They resisted a large amount of thrust; and there was no doubt the weight upon the pier-base of the first bridge was so insignificant that, if the whole of the load acted upon one half only, the pier would be stable. A light pier was enabled to bear the weight by the resultant forces being made to pass near its centre. One method of accomplishing this was by means of the flat girder arches acting as struts: these were very stiff, and the piers might be pushed hard against them, without producing a serious upward strain upon the girder not loaded with its full load. It was evident that in the second bridge there was no tension, in hot weather, upon the top ties of the middle arches. It was only to be got by such a contrivance as had been introduced in the first bridge, or by riveting up the girders at the hottest time of all. The numerous India-rubber connectors, $3\frac{1}{2}$ inches diameter and $1\frac{1}{2}$ inch thick, might be subjected to a constant strain. The range of length to be provided for in each of the spans was about $\frac{2}{3}$ inch, and there were four sets of India-rubber rings to be dealt with. If these expanded amongst themselves to the extent of $\frac{2}{3}$ inch, and a pressure was still maintained upon them, there would never be any compression upon the ties; while if the Engineer thought tension was necessary, that afforded an additional method of keeping a tolerably vertical resultant upon the piers. The same result might be effected by a strong, deep top member. This would lead to a considerable increase of weight being thrown upon the unloaded arch. Instead of cutting this member down he would have carried its full thickness over the top of the arch. It appeared the governing height of the structure was the headway required at the land openings. At the middle of the first arch, with the

gradient of 1 in 60, there would be an increase of height of 3 feet. That would have enabled the whole roadway to have been raised 3 feet, and it might easily have been accomplished.

The introduction of light wrought-iron arches in large spans without diagonal trussing was first tried by Mr. Fowler in this bridge. He did not remember a previous instance beyond the Westminster Bridge arches, which were of small size; but in that case there were no heavy locomotive engines to be provided against. Wrought-iron arches of 100-feet span were introduced twenty years ago, and the span was gradually increased to 450 feet; but there were ties, and, therefore, a means of vertical and diagonal bracing; and by the use of these the arch was kept in proper shape. Mr. Fowler had departed from that system; in this instance there was a boldness of design which had been very successful.

Mr. Benjamin Baker was not surprised that the innovations introduced in the widening of the Victoria Bridge had provoked criticism. In the first bridge the arched rib was of uniform section throughout, whilst in the widening it was reduced in section towards the ends, as a girder, the maximum transverse strength at the centre of the span being three times its maximum strength elsewhere. If the hypothesis on which that work was constructed were correct, he did not see how to avoid the conclusion, that the original bridge, in common with most other arched viaducts, was altogether wrong. Sufficient evidence had been advanced, in his opinion, to show that the departure from precedent in this instance was not attended with advantage.

Referring to the diagram showing the distribution of the load (Plate 6, Fig. 11), and the manner in which it was assumed to be carried, it was seen that the ironwork was supposed to carry the load partly as an arched rib simply, and partly as a continuous girder of varying depth, and the proportions in which it acted in the several capacities appeared to him to have been determined arbitrarily. Assuming, however, that such a distribution could be obtained in practice, he found, upon calculating the change of form which the ironwork would undergo in such a case, that the movement of the piers would be considerable, and the deflection much greater than was indicated—at least two or three times as great. He contended that it was physically impossible for the ironwork to act in the way shown on the diagram while the deflection was such as was stated. There could be no better authority than the structure itself, as to the mode in which the work was done. The ironwork showed that it was doing duty simply as an arch, and that it was not acting in the roundabout way indicated on the diagram. Ample evidence was afforded by the original bridge of the practical immobility of the piers; for if each pier had moved but $\frac{1}{8}$ inch, that movement would have been registered by an additional

deflection at the crown of $\frac{5}{8}$ inch—an amount which could not possibly escape observation; and yet the additional strain thrown on the metal by such a movement of the piers would not exceed 7 cwt. per square inch.

His attention had been directed some months ago to the anomaly presented by the two bridges, and he had made a careful analysis of the strains to which each bridge was liable. He first ascertained that the piers were immovable by observing the deflection. That in the original bridge did not exceed $1\frac{1}{16}$ inch—the amount due to the compression of the arched rib, and consequently there was no balance to show movement of the piers. He next satisfied himself that, after the rounded shoe had taken its bearing, under a full load, no further movement need be anticipated. The radius of the end was too large, and the co-efficient of friction was too great, to admit of further movement. The rounded shoes and cotters had done important duty, in securing uniformity of strain under a full load; and beyond that, it was rather an advantage that they should not act. Having arrived at this point, the solution of the problem was comparatively simple, and the results reliable. The case was that of an arched rib fixed at the ends, and with stable piers. At the mean temperature the maximum strain, with a rolling load of $2\frac{1}{2}$ tons to the foot, uniformly distributed over both lines, would be 3 tons 14 cwt. per square inch. The maximum bending moment occurred at the unloaded haunch of the arch, when about $\frac{6}{10}$ths of the span were fully loaded. At the mean temperature, the resulting maximum strain would be 3 tons $16\frac{1}{2}$ cwt. per square inch. The maximum bending moment at the centre of the arch would occur when about one-half the span at the centre was fully loaded, the two haunches being light; and the maximum resulting strain at the crown of the arch would be 3 tons $16\frac{3}{4}$ cwt. per square inch, at the mean temperature. These strains would be increased by the expansion and contraction of the ironwork at extreme temperatures. It was considered that $\frac{1}{2}$ inch variation in length for each 100 feet was sufficient allowance for the range of temperature in this climate, and on that assumption the strains at extremes of temperature would be increased to 4 tons $6\frac{1}{2}$ cwt. per square inch at the haunch, and 4 tons $9\frac{1}{3}$ cwt. per square inch at the centre of the arched rib. It appeared then, that the maximum compression on any cross section of the arched rib averaged under $3\frac{3}{4}$ tons per square inch, and that the maximum stress on any part of the cross section was under $4\frac{1}{2}$ tons per square inch. If any question arose as to the strength of the original bridge, it could only be with reference to the factor of safety. It would be seen that the relative proportions of the several parts were correct. The horizontal girder, combined with the spandril-filling, was of the requisite strength to relieve the arched rib of the excess of strain at the haunch.

Returning to the widening of the bridge, as the spandril-fillings did not possess any bracing power, the detail being different to that in the original bridge, the load would be carried partly by the arched rib as an arch proper, and partly by the arched rib and the horizontal girder as continuous girders. By calculating the relative deflection of the two systems, it appeared that the arched rib carried $\frac{9}{10}$ths of the gross load as an arch, the remaining $\frac{1}{10}$th of the load being carried by the continuous girders. At a mean temperature, and with the same rolling load as before, uniformly distributed, the maximum strains would be 3 tons 15½ cwt. per square inch at the crown of the arch, 5 tons 17 cwt. per square inch at the springing, and 1 ton 19 cwt. per square inch on the horizontal girder over the piers. Under the most unfavourable condition of loading, the maximum strain at the crown of the arch would be increased to 4 tons per square inch. The influence of changes of temperature in this instance was very important. The horizontal girder being in one piece, nearly 1,000 feet long, it followed that, if it expanded at all, it would do so towards the two land openings. In that case it would have to carry the tops of the piers and the crowns of the arches with it. If the tops of the piers were movable this might possibly happen, and then the increased strain due to the changes of temperature would attain a maximum at the end arches of the viaduct, and be equal to 3 tons 10 cwt. per square inch. As the piers were not movable, this expansion and contraction of the horizontal girder could not take place; and, that being so, the strains on it with the same range of temperature as before would be 1 ton 6 cwt. at the centres and 2 tons 14 cwt. over the piers. The final maximum strains on the several portions of the ironwork under the worst conditions would be as follows:—4 tons 11 cwt. per square inch at the crown of the arch, when the centre half of the span was loaded and the temperature high; 6 tons 14 cwt. per square inch at the springing of the arch, when fully loaded and the temperature low; and 6 tons 15 cwt. tension per square inch on the horizontal girder, under the same conditions. These amounts were much less uniform than those obtained for the original bridge, owing to the mass of metal which had been thrown into the centre of the arched ribs for the widening. Apart from the results due to a false hypothesis, it appeared that the constructional inferiority of the widening, as compared with the original bridge, was evident in at least two particulars. Thus a large proportion of metal had been thrown into a horizontal girder not free to expand or contract, and where, consequently, it was exposed to perfectly useless strains, amounting to 60 per cent. of the total stress which should have been incurred by the metal; whereas, if the same weight of iron had been placed in the arched rib, it would have been equally effective as far as resistance was concerned, and the strains from changes

of temperature would have been neutralized to a great extent by the rise and fall of the arch. Again, a considerable percentage of the gross load was carried by a girder 4 feet 6 inches deep; whereas, had the arched rib been cottered up judiciously, as was done in the original bridge, that load would have been supported, with a far less expenditure of metal, by an arch of 17 feet 6 inches rise.

Mr. F. W. Sheilds agreed that these bridges ought to be considered in the light of a perfect arch throughout, rather than as combined arch and girder. With respect to the horizontal beam on the top, with radial bracing in the spandrils, he thought it would be a more advantageous principle of construction to lighten the top longitudinal beam, throwing the metal so saved into the arch, if a great amount of stability were required, and to unite the longitudinal beam and arch by a more perfect method than could be obtained by the radiated spandril bars. He thought this union would be best effected by a spandril formed of solid plate or lattice-work, which would distribute the pressure of the passing load, especially that from the driving-wheels of the locomotive, over a considerable length of the arch, rather than by transferring that pressure to single points on the arch by means of detached and oblique connections, such as the radiated spandril-bars.

The bearing of the arched rib upon the piers and abutments naturally drew attention to the contrast between the curved skewback in the original structure, and the ordinary skewback adopted in the adjoining bridge. Now, would such an arch move upon its bearings? It seemed to him that when once fixed in its place, it would never afterwards be strained to such an extent, either at the top or at the bottom, as to be raised off its bearing. In an ordinary skewback, it was evident that if the crown of the bridge was depressed, either by contraction in cold weather, or by a load on the top, there would be a tendency to an increase of pressure on the lower end of the bearing, and a diminution of pressure on the upper end; and the opposite effect would occur when the bridge was expanded from heat; and this would take place whether the skewback were curved or straight. But the arch would not, in practice, alter its position, either by rolling round the curved bearing, in the one case, or by partly rising off its seat in the other; and he, therefore, preferred the straight bearing as being the simpler construction. In the case of a bridge with many arches, he thought it would be better to make the springing over the head of the piers of iron rather than of masonry, so as to unite the arches perfectly together, and distribute the strain on any one loaded arch over the adjacent arch or arches. He thought, moreover, that there were additional advantages accruing from this arrangement. Besides obtaining a construction of homogeneous material, the fitting of the bearings or springings in the workshop could be done with a

greater degree of accuracy, and the strain on any loaded arch would be thereby better distributed, not only on its own bearings, but also over the adjacent arches, as was shown by the latter rising at the crown in the manner mentioned in the Paper.

Mr. G. W. Hemans asked whether Mr. Sheilds suggested that the continuation between the bearings of the two arches should slide on the top, or be fixed to the masonry of the piers?

Mr. Sheilds: the bearing would not slide in practice, though when under heavy pressure it might make a slight pier bend over at the top, but it would form a vertical bearing on the top of the pier, and the thrust from one arch would be transferred more perfectly to the other. He held that the unloaded arch should aid in supporting the loaded arch, by means of a more perfect connection over the heads of the piers. There was no doubt that one of those slight piers alone would be insufficient to support the weight of a loaded arch if the adjoining arch were removed. He would therefore ensure, by perfect fitting and homogeneous construction, that when one arch was loaded, the metal of the adjoining arch or arches should be brought into strain to support it.

Mr. J. M. Heppel quite concurred with those who thought that there was little substantial difference in the mechanical condition of these structures. It was almost evident, from the deflections which occurred when placed under load, that there could have been no material difference in the way the strains were propagated through them. He thought there was a close analogy between the principle adopted in the original bridge and that of a stiffened suspension bridge. Mr. Wilson had said that the arch, by means of the peculiar springing, was placed under such conditions, that the strain through it was always uniform over its section: and it seemed to him that it assumed the condition of a chain, prevented from deflecting by some stiffening adjunct, such as a horizontal girder. In reference to this it had, however, been remarked, that the horizontal girder was in fact not acting very effectually, as was proved by the slight deflection that took place. In that opinion he concurred. It seemed, further, that whatever might have been predicted, *a priori*, the experiments showed from the trifling deflection of the horizontal girder, that it could not be doing much work simply as a girder. The stiffening of the arch, which seemed to be perfect, was, he thought, chiefly due to the connection of the horizontal member with the arch by the spandril-filling. This, to a certain extent, answered the purpose of the bracing ordinarily inserted between the top and bottom members of a beam.

He thought this bridge would have been improved, if a portion of the metal had been taken out of the horizontal member and added to the arch, and the connection between the two had been made more perfect, either by diagonals or by a continuous web. If the details of the deflections were examined, it would be found

that the action resembled that of a stiffened suspension bridge, as was shown in the case of the Clifton Bridge.

The extent of the alterations of the spans was indicated by the rise of the unloaded arch, which was a scale that measured the motion in the springing of the arch. He thought that, in this case, the rise of the unloaded arch was about twice the horizontal motion at the springing, and that the piers at the springing moved backwards and forwards about $\frac{1}{16}$th of an inch, which proved that they possessed a great amount of stability. This did not depend upon the through tie; as before that could act effectually the piers must move through a considerably greater space. In fact, it seemed to him that Mr. Fox gave the piers less credit for stability than they deserved, and that, though the horizontal member might be capable of giving stability, it was, in the actual condition of things, not much drawn upon. Mr. Brereton had stated, that as long as the resultant was kept well within the base of the pier, no danger need be apprehended: but he thought so large a deviation as that which Mr. Phipps attributed to it would produce a serious disturbance of the distribution of the load on the foundations. He had occasion to investigate the question in the case of the proposed bridge over the Frith of Forth, where it was important to know what maximum amount of pressure would be brought to bear on any part of the foundations; when it appeared, that if the resultant were to fall so much as halfway between the centre and the edge, its amount at the latter point would become trebled. In some cases this might be serious; but he believed the London clay was a stubborn material, capable of supporting great pressure, and it was possible that a larger deviation from the centre might exist without any fatal disturbance.

Mr. Brereton remarked that half the size of the present pier would have been sufficient to carry all the weight that came upon it.

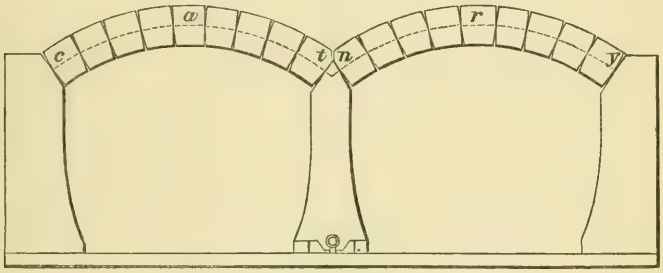
Mr. E. A. Cowper hoped the Authors of the Papers would lay down the principles on which these bridges were constructed. It would be seen that, in the original bridge, the long girder, with India-rubber washers, was in balance, and could move either way, on a slight strain being applied longitudinally; therefore it was impossible it could do any real work in maintaining the bridge. He did not think this girder put the half-arch into the condition of a cantilever, having the rib of the arch in compression and the girder in tension; but that it slightly added to its strength by increasing the depth of the arch by means of the spandril-filling. In the second bridge, when the top girders were riveted together, they were in the same state of tension at each end, and therefore in balance; and if one arch was depressed, the next would rise, and there would be no perceptible alteration in the horizontal distance

between the crowns of the arches, and no strain on the top girder. The piers would bend if there was more pressure against one side than the other. He had been on the top of a chimney which rocked an inch in a moderate wind; some chimneys would vibrate as much as 4 inches at the top; and he had known a large square chimney to move $\frac{1}{8}$ inch at 16 feet from the ground. With a foundation on clay at the bottom of a river, a high pier, with a moderate base, would certainly spring some distance, under a greater pressure on one side than on the other. If, however, it were now considered that the piers were infinitely strong and stiff, which was assuming an impossibility, it was clear that no horizontal tie could do any work, as its length would not alter. Nor with such piers could the half arches act as cantilevers, unless the arch were cut at the key-stone, and a piece were taken out to allow each half arch to hang from its pier as a cantilever, so that the horizontal tie could come into action when the load came on to the bridge. It was quite possible to imagine such a structure, though impossible to make it; indeed, if it had been possible, it would have been inadmissible; no engineer would dream of running a heavy load off the end of one long deflected cantilever on to or against the end of another long undeflected cantilever. It was a pity that, when the Institution was furnished with the general particulars of successful works, the theory of their construction was often left out, and the practical results only brought forward. In the present instance it would have been interesting to have heard by what principles the Engineers had been guided. He ventured to say that no bridge could be considered economical or safe, if the line of strain passed outside the rib or stones; and if so, it became of the greatest importance to ascertain the exact curve that the strain took, when the bridge was in any one condition of loading that would occur either under ordinary or extraordinary circumstances. This was precisely the same as in the Inverted Arch Bridge, which he had formerly described;[1] and the curves of strain that had to be provided for might be ascertained by the process he then mentioned. He maintained that the rib of the bridge should be made to contain all such curves within it: then, if it was constructed with flanges, and each flange was made capable of taking the whole strain, the rib would be safe, and perfectly stable if properly stayed side-ways and on a good foundation. By such a mode of calculation a perfectly stable rib could be constructed: it had been put in practice largely by himself in calculating the Richmond and Barnes Bridges, and numerous others; and nothing had occurred to shake his confidence in this mode of calculation, though he knew it was not commonly used. The only useful

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 281.

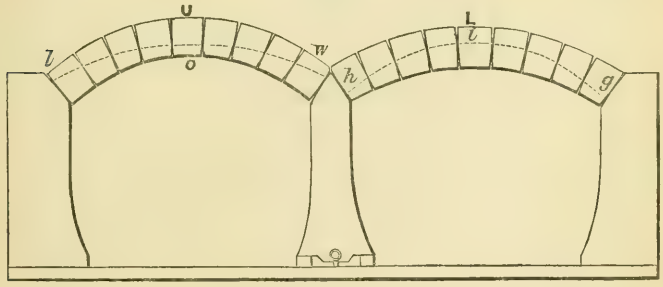
support that could be afforded by the spandrils was that, taking advantage of the metal being there to support the platform, it might be placed in diagonal lines, so as to assist, to some extent, in preventing the arched rib from bending. He believed that was the true way in which to calculate the metal in a bridge of this kind, and he thought if wrought iron must be used, it ought not to be considered as any better than cast iron, for it was not so able to resist compression, and this was the strain that the metal of an arched iron rib was called upon to bear. The rough wooden model (Fig. 1) would show the way in which one arch

Fig. 1.



supported the other when one arch was loaded and the other not. The centre pier was capable of motion on a pin at the base, but was supported by blocks of India-rubber, to represent the condition of a pier capable of some motion. The arches were catenary curves, and the arch-stones were slightly rounded on their beds, so that they could roll a little, to make the motion visible to the eye. The line of strain or line of contact of the rounded beds was a catenary curve, *c*, *a*, *t*, *n*, *r*, *y*, and it passed through the centres of the stones. But if the first arch was loaded, and the second arch left unloaded (Fig. 2), it would be found that the catenaries

Fig. 2.



were distorted to a considerable extent;—and that while the first

arch was flattened the second was raised. The exact line of contact of these stones was shown to be on the line *l*, *o*, *w*, *h*, *i*, *g*, on the faces of the stones in the model. Now it was evident that the first, or loaded arch, L, was flattened by the load, and the outside edges of the stones thereby brought nearer together, so that the line of contact *h*, *i*, *g* was higher at the key-stone. It also appeared that the same flattening of the curve threw out the bottom edges of the stones against the skewbacks and lowered the line of contact at the springing, raising the curve of strain *h*, *i*, *g* higher than before. In the second, or unloaded arch, U, the reverse took place; so that the line of strain *l*, *o*, *w* was flattest in the arch which was highest, and the line of strain *h*, *i*, *g* was highest in the arch which was flattest. This would be so whether the arch were of stone or of iron; though in the case of a stone bridge the distortion would be less, owing to its greater weight. The unloaded arch supported the thrust of the loaded arch because the line of contact *l*, *o*, *w* was a flatter curve than the line of contact *h*, *i*, *g* of the loaded arch; therefore the horizontal thrust of the two was the same, and they were exactly in balance, and perfectly stable, the pier being free to move when strained; and if he took the blocks of India-rubber away from under the pier it would still stand. It was hardly necessary to observe, that in a stone or iron arch a very small motion or distortion would at once bring the curved line of strain to one side or the other of the rib; so that a minute yielding of the centre pier would enable the thrust of one arch to balance the other. The more clearly to show that the stringer, or horizontal girder along the top, could not do much duty, he would fasten upon the crowns of the arches in the model a stringer of paper with two pins, so that if the distance between them were altered at all it would tear away from these pins; but on repeatedly depressing first one arch and then the other, it would be seen that the paper was not in the least affected; therefore there could be no strain upon the horizontal tie. Again, if the paper tie were formed to represent the spandril-filling, as well as the tie, and were also fixed to the skewbacks between the arches, it would still move with the arches, and there would be only the smallest possible motion at the bottom of the spandril. In conclusion, he would draw attention to the admirable cast-iron bridge by Telford over the Birmingham Canal, called the "Summit Bridge;" to Southwark Bridge, constructed by Rennie; and others that were made when iron-founding was young in this country; and he must say that, whatever special causes there were for the Victoria Bridges being made of wrought iron, he maintained that cast iron was the right material for arched bridges of large or small span; and, now that iron-founding and fitting could be done in such perfection, they were undoubtedly the cheapest to make, the easiest to

fit, and, owing to their greater weight, the firmest when up; besides which, they would last much longer.

Mr. William Bell remarked, through the Secretary, that if the piers and abutments were absolutely immovable, a simple arch rib would have been sufficient, because the increased thrust arising from loading one of the arches would have been resisted by the immovable springers, while the variations of temperature would simply have caused a variation in the rise of the arch-rib, and would have produced no internal strains, except those arising from the resistance to rising or falling of the top platform, which might have been made of small amount. If, by the increase or decrease of the forces acting on them, the piers and abutments were supposed to be subject to small displacements, either from their being considered as elastic beams of masonry, or from the compressibility of their foundations, the question became complex, and could not, he thought, be definitely answered, without an intimate knowledge of the amount of these small displacements. Referring, first, to Sir C. Fox's design, if the bridge were held to consist virtually of a series of cantilevers, the horizontal beam at the top of any semi-arch might be considered as a tie-beam, and thus must be sufficiently strong to sustain, by its tensile strength, the horizontal thrust of the loaded semi-arch with which it was connected. This semi-arch would then be subjected to the same internal strains, as if, instead of the tie-bar, the horizontal thrust had been balanced by the thrust of the opposite semi-arch. But with these tie-bars, the bridge would consist of piers and abutments, with cantilevers projecting from them, the under parts of these cantilevers having the shape of semi-arches. Each arch might thus theoretically be supposed to be severed at the crown, and if the piers and abutments had sufficient stability, without their being absolutely immovable, an expansion joint might be placed there, and no internal strains would be produced from the variations of temperature. This construction would have the advantage, that arrangement might be made for any pier or abutment to settle considerably without thereby endangering the safety of its neighbours; but it should be remembered, that to obtain this advantage, the top horizontal beam must be made thoroughly efficient as a tie-bar, in which case it would require a sectional area not much less than that of the arch-rib itself.

The special purpose, however, as he understood it, of the horizontal beam, and which was first carried out in Mr. Fowler's design, was that of making it resist the additional horizontal thrust produced by loading any of the arches, where, from the situation, it was obvious that a system of direct ties could not have been introduced at the springings of the arches.

The piers and abutments being supposed capable of movement, if

the temperature were invariable, and the horizontal beam simply laid on the top, without being connected with the arches or the piers, the loading of one of the arches would produce a compression of the arch rib, with a diminution of its rise, and a horizontal thrust at the springing of the arch. This horizontal thrust would push the piers outwards, until it was balanced by their increased resistance to lateral movement, and the resistance of the arches to alteration of their form, which last would be modified by the resistance of the top platform to bending consequent on the alteration of rise of the arch.

Referring to Sir C. Fox's design, if the horizontal beam were firmly connected with each pier, the piers could not be pushed outwards without the beam being extended along the loaded span, and compressed along the unloaded spans, thus introducing forces of tension and compression, which would assist the forces of the piers and arches in neutralizing the thrust of the loaded arch. It should be borne in mind, that there must be a certain movement of the piers before these forces could be called into action. If now the temperature was supposed to vary, the horizontal beam could not change its length without causing displacement of the piers, the amount of this displacement being determined by the condition that the forces generated in the beam by alteration of temperature should be equal to the resistance of the piers and arches to further displacements, and thus the strain due to change of temperature might be much less than what would happen if the horizontal beam were supposed to be fixed at each end. There would also be a mitigation of the strain, arising from the fact of the rather greater extensibility and compressibility of riveted as compared with solid iron. Very little of the strain could be taken up by the beam bending vertically or laterally, as it would be found that it required considerable sinuosities to produce an appreciable alteration of length. If the horizontal beam were connected with the centres of the arches only, it would also be indirectly connected with the abutments, by means of the outside semi-arches, and the strains arising from changes of temperature would then be due to the difference between the motion of the abutments, including the giving of the end semi-arches, and the motion of the end of the beam supposed free, on a length of beam reaching between the crowns of the end arches. In this case the strains would possibly be greater than if the horizontal beams were connected with the piers.

Now suppose, as in Mr. Fowler's design, that the horizontal beam was severed over each pier, and the parts connected together by springs, capable of extension or compression; and suppose these springs were of such force as to double the compressibility or extensibility of the beam; that was, if a force of 1 ton were applied to the ends of the beam, the amount by which it would be compressed or

extended would be double that which would take place if the beam were riveted up from end to end. Such a beam, if fixed at the ends, and subjected to changes of temperature, would only encounter the halves of the strains which would happen if the beam were in one piece, because the parts of the beam could now alter their lengths by compressing or extending the springs, until the forces of spring and beam were equal, which, since they were supposed to have equal extensions, would happen when the strain was half what it would have been if the beam had been in one piece. By the use of these springs, then, the strains arising from changes of temperature would only amount to one-half what they would be under other circumstances; but, on the other hand, the amount of motion necessary before a given amount of force could be got out of the beam, must be double what would be necessary if the beam were in one piece: thus with beams constructed with springs, the piers must be supposed to have a greater amount of motion before the force necessary to balance the thrust of the loaded arch could be obtained. But the necessary amount of force could also be got by doubling the sectional area of the beam. It was easy to see that by the use of springs of less force than in the above example, the strains arising from temperature might be reduced still further; while, on the other hand, the motion of the piers must be supposed to be increased, or the sectional area of the beam made greater, in order to get sufficient force to balance the thrust of the loaded arch, and *vice versâ* with springs of greater force.

The main element then in the solution of the question, was the amount of motion of the piers and abutments, without a knowledge of which it would be idle to make detail calculations; but if, treating the piers and abutments as elastic beams, there existed reliable data on the stiffness of built-up masonry, and the compressibility of foundations, there was sufficient knowledge of the properties of iron arches and girders to allow of a definite solution being arrived at.

Mr. E. W. Young was acquainted with some of the reasons which had guided the Engineer in the form of construction adopted in the widening of the Victoria Bridge.

It had been remarked that two engineers had adopted different principles of construction in a similar case; but this was not exactly the fact, and he wished to point out in what respects the two cases were different. The span, the rise of the arch, and the load to be carried were the same; but in the widened portion a junction with old work had to be effected, and a very wide bridge made, which somewhat altered the conditions. In the first place, there was greater rigidity and stability in each pier, as a whole, in the wider bridge, and further, as in the junction with the old work, great expense would have been incurred in making coffer-dams and con-

structing piers, similar to those of the old structure, the engineer advocated cylinder foundations. They were adopted, and piers built, which, though not so stable as the older piers for each yard of their length, were yet very firm from their great length. However, it was determined, if possible, to make the ribs better able to resist the effect of unequal loading. With a view to this, the ribs were deepened in the centre, and a large proportion of metal put into the flanges, so as to give a great amount of stiffness to the unloaded arch, to enable it the better to resist the thrust of the loaded arch. In the original bridge the depth of the rib was 3 feet 6 inches throughout, and there were two webs: in the widening there was only one web, but the rib was 4 feet 6 inches deep at the centre of the span, and there was much more metal in the rib at the centre than at the haunches. He had compared the stiffness of the two ribs; multiplying the area of the metal in the flange by the depth of the rib, 280 represented the stiffness of the rib in the widening; whereas by the same process, the relative stiffness of the original bridge would be found to be only 150. Another advantage of making the flanges of the rib of greater sectional area at the centre was that the curve of equilibrium might pass through either the top or bottom flange without causing a dangerous strain upon the metal. The area of the rib was 64 inches both in the top and the bottom flanges, so that the curve of equilibrium could pass through either flange without injury to the metal. The advantage derived from the stiffness of the rib was this:—that in the unloaded span it offered resistance to the horizontal motion of the pier caused by the loading of the adjoining span. The motion in the pier caused by the rising of the unloaded arch to the extent of $\frac{1}{8}$ inch, which was the rise produced by the test load, represented a horizontal motion of the pier equal to $\frac{1}{20}$ inch. It was expected that this bridge would act as an arch, on account of the great stability of the piers due to their width; but the bridge was, nevertheless, made strong enough to act as a continuous girder, supposing the extremely unlikely circumstance to occur of the bridge being loaded with locomotives over the whole width of one archway. It would not then fall down, even if the pier were to be pushed over; for then the ironwork would act as a continuous girder. Another difference in the two structures was with regard to the loading. The earlier bridge had a heavy platform, comparatively speaking, so as to keep the line of thrust within the piers; in fact, the dead load was $1\frac{1}{4}$ ton per foot run; whereas in the latter it was only three-quarters of a ton. This heavy dead load in the first bridge rendered a greater area of metal necessary to carry it than was required in the second. In fact, in the one case, he calculated the weight of metal in a span to be about 100 tons for each line of way, and, in the other, about 130 tons. That, of course, affected the

question of cost. Then there was the heavier platform of the first bridge, which also added to its cost, and, as he considered the design of the pier in that bridge more expensive than the cylinder piers, he thought the last constructed bridge the more economical of the two. Under the alternations of heat and cold the horizontal girder was subjected sometimes to a compressive, at others to a tensile strain. This simply caused the rib to rise, but it did not prevent the bridge acting as a continuous girder, because, before the bridge could fall down, it would have to put a tensile strain on the bottom flange, or a compressive strain on the top flange exceeding the strength of the iron. It had been said that the ribs could not act as a continuous girder because of the spandril, there being no web; but he considered it as a cantilever having one straight top member and one curved bottom member, and, as the point of contrary flexure would not be in the spandrils, there was no necessity for a web.

An opinion had been expressed that it would have been better if the spandril-bars had been perpendicular: but there was one advantage in placing them in the position they occupied, inasmuch as the curve of equilibrium became the segment of a circle, because the pressure was perpendicular to the rib. As in a cylinder sunk in water, the curve of equilibrium of pressure passed through the centre of the metal of the cylinder: so in these bridges the curve of equilibrium was the segment of a circle, and not a parabola or a catenary. He wished to show that the horizontal girder resisted the thrust of the arch, because, supposing the horizontal girder to do its duty, before the rib could break the pier, it must push it over. In the model brought forward by Mr. Cowper, he thought if the cardboard had been fastened at the lower end, it would have come into play, the lower part of the cardboard being now free to move.

In this case there was a bending motion; and if a perpendicular line were drawn down the face of the pier, the moment one arch was depressed, that line would be bent, showing thereby that the pier would have to break. In the more recent bridge, the cast-iron standard was bolted to the bottom of the horizontal girder, and unless the pier were broken, it could not be pushed over; on that account, he considered the horizontal girder did duty in helping to resist the horizontal thrust of the rib.

Mr. Cowper asked if the pier was supposed to be stiff? If it had a strong vertical girder he admitted Mr. Young's premises.

Mr. Young: It was stiff to a certain extent, and it must be remembered that motion to the extent of the $\frac{1}{20}$th part of an inch at the springing, would produce a larger movement at the top of the pier. He did not say that it made an effectual resistance; but to some extent it helped in resisting the horizontal thrust of the rib. If he had now to design such a bridge as this, he should make the ribs of cast iron.

Mr. J. A. Longridge expressed a hope that the Authors of the Papers would, in their replies upon the discussion, state the specific reasons which led them to adopt wrought iron instead of cast iron for an arched bridge. He thought stone was the proper material to use except under circumstances where it could not be got, or only obtained at a great expense: but if iron were used, he considered cast iron the more suitable material, inasmuch as cast-iron resisted compression better than wrought iron, and all the material of the arch was in compression. Besides, cast iron was much cheaper, and for the same cost a greater mass of metal could be put into the bridge, thereby adding considerably to the stiffness, which was an important element in railway structures. He had no confidence in the combination of the girder and arch principle. He was of opinion that the horizontal girders did not strengthen the bridge, and that if the same amount of material had been put into the arch ribs it would have made a stronger bridge. He could not think that wrought iron had been adopted in these structures, and others now in progress, from any fear that the foundations might fail. If the foundations were bad, the girder was the proper form of bridge. He should like to be informed how the motion of $\frac{1}{20}$ inch in the abutments was measured; deducing it from the vertical rise of the arch was, he thought, fallacious; but that amount of motion could do no harm, even if it took place in a stone bridge. In conclusion, he expressed his decided opinion, that the adoption of wrought iron in these bridges was an entire mistake.

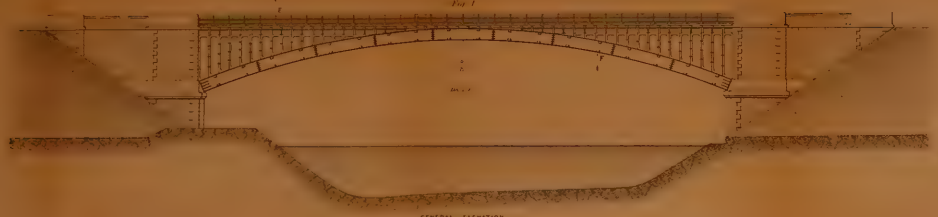
Mr. G. H. Phipps asked whether, in loading and computing the strains on these arches, every line of railway had been taken, as bearing its full train-load, or whether only one line at a time had been taken. He should have thought the computations would have been founded upon the full loading of all the lines.

Mr. Young had assumed every line to be loaded with locomotives, and had endeavoured to show that, under that condition of loading, the bridge could not fall down, and he believed that, even when all the lines of rails were thus loaded, it would still act as an arch.

Mr. J. D. Baldry said that a sentiment similar to that which animated Mr. Longridge had passed through his own mind; and it occurred to him that it might be interesting to place on record the particulars of a cast-iron bridge, of a larger span than the bridges under consideration; and by permission of Mr. John Fowler, Past-President, Inst. C.E., he would do so. There were two bridges of this description—one on the Severn Valley Railway, the other on the Coalbrookdale Railway, and both were erected over the river Severn. Plate 7 represented a bridge with an arch of 200 feet span, having a rise of 20 feet, and it was probably the cheapest bridge of the kind ever erected. It was built

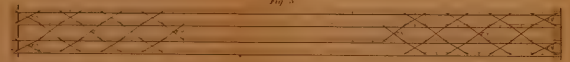
SEVERN VALLEY BRIDGE.

FOR CARRYING THE COALBROOKDALE RAILWAY.

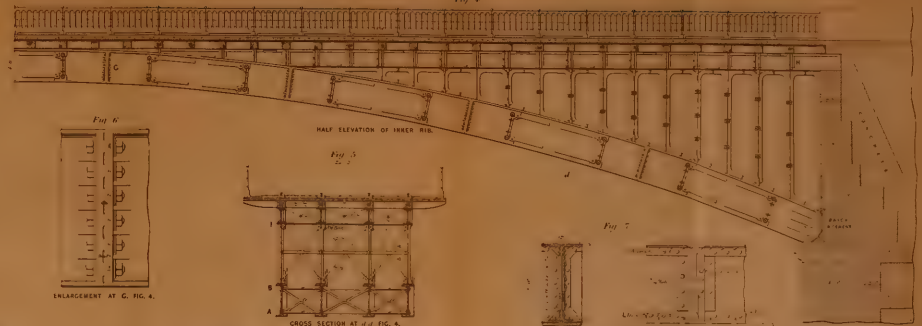


GENERAL ELEVATION.

GENERAL PLAN, SHOWING HORIZONTAL BRACING IN MAIN RIBS.



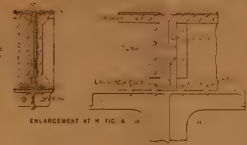
PLAN OF HORIZONTAL BRACING ON BOTTOM OF W. I GIRDER



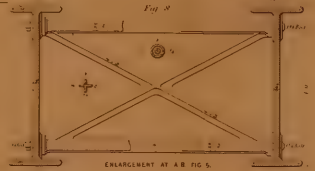
HALF ELEVATION OF INNER RIB.

ENLARGEMENT AT G. FIG. 4.

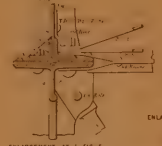
CROSS SECTION AT d d FIG. 4.



ENLARGEMENT AT W FIG. 4.



ENLARGEMENT AT A B FIG 5.



ENLARGEMENT AT I. FIG. 5.

ENLARGED SECTION AT BB FIG 5

SECTION AT

subsequently to the Victoria Bridge. At first it was proposed to make the arches double, coupled together so as to form hollow voussoirs: but that plan was abandoned, partly because of the simplicity of construction of a single arch, and partly because a less amount of metal would allow the necessary depth, which should preserve the line of pressure within the arch, clear of the top and bottom flanges. Each arch was cast in nine parts, each piece weighing between 5 and 6 tons, and braced together as shown in Plate 7, Fig. 8, with two cast-iron frames having strong bolts, which were keyed up closely. The ends of these segments were planed and bolted together, the upper and lower bolts being of larger section than those in the middle. Fig. 6. The strain per square inch was calculated at $2\frac{1}{2}$ tons; this became afterwards somewhat increased by the addition of the full thickness of ballast. The casting into which the heel of the arch was placed was similar to the one used in the Victoria Bridge, Pimlico, except as to the steel keys. With regard to the use of this shoe there was no doubt that, during the course of erection, it was of great advantage, because it enabled the arch to take its proper bearing and adjustment, and facilitated the erection. In the Victoria Bridge he believed the steel keys or wedges were introduced to give the exact position; but in the present bridge there being no keys, the shoes were secured to the abutments by heavy bolts. After erection, the shoe ceased to be of use, so far as its circular form was concerned, because the rise and fall of the arch was not sufficient to give motion in the shoe; for instance, a variation of temperature of 100° would cause a movement in this bridge of 200 feet span, of about $2\frac{1}{2}$ inches at the crown. Now the rotation of the heel would be, supposing no friction, about $\frac{1}{16}$ inch; but the friction of the surface being considerable, this motion did not take place; indeed, a much larger amount could be absorbed by the elasticity of the metal; therefore, the only practical result from the rise and fall of the arch was the transference of something less than half a ton per inch, from the upper to the lower limb, and *vice versâ*. The next point to be noticed was the straight line which carried the load. In this case a wrought-iron girder was used. One reason for this being made of wrought iron was that if an exceptional load came on at E, Fig. 1, and the other side were unloaded and perhaps denuded of ballast, there would be an upward thrust at F, Fig. 1; but, by the close connection of this wrought-iron girder with the cast-iron arch, there was a great depth of girder to resist it, the wrought iron being in tension. This was not a case likely to happen, but he thought there was no harm in providing for it, as it was a weak point in these bridges. This girder was strengthened in the vertical web, at the points of contact with the columns, at H, Figs. 4 and 7, to resist the hammering effects of the passing loads.

With regard to the spandril columns which transmitted the load, some were rather long—about 17 feet; they were 4 feet apart, and strengthened at intervals by struts. These struts were continued through the bridge (Figs. 4 and 5), and being aided by vertical diagonal bracing, gave lateral strength to the bridge itself.

One of the essentials in constructing bridges of this description, was that the arch should be kept to its work by means of bracing and strutting, somewhat of this nature; which, more than by any other means, would prevent the vibration so much complained of, but which was inseparable from iron bridges. He had nothing to say in favour of this particular bridge, except that it had been carefully studied, and he thought every part was doing its proper duty: he might mention that the deflection from the passage of a train had recently been observed to be $\frac{3}{10}$ inch. He would endorse what had been said, as to the use of iron where masonry could be obtained; but it was for the engineer to consider, when the work was before him, whether he should adopt metal or stone, and whether cast iron or wrought iron. There were often excellent reasons for using wrought-iron arches, particularly where a bridge was of several spans, and the piers were narrow, as in a strong tide-way; but for single spans, he had no hesitation in saying, that the mass of metal that could be placed in one thickness gave a great advantage to cast iron, irrespective of the question of cost. Beyond certain spans, metal took the place of stone by necessity; but, for small spans, it appeared to him that, taking into consideration the vibration and the disturbing forces of the moving load on light bridges, stone was the proper material.

Captain Tyler said it had been his duty to inspect and test the bridge over the River Severn which had just been described, and he was happy to bear testimony to its excellence. It was, in his opinion, a great improvement upon the Victoria Bridge previously constructed over the River Thames. It combined stiffness with cheapness in a remarkable degree, and he had been, for that reason, much struck with it. He thought there was an advantage in the employment of cast iron, in the place of wrought iron, in bridges of this description. In the first place, wrought iron was less durable, and required more painting; in the second place, cast-iron bridges, even of large spans, could be constructed with greater cheapness; and in the third place, cast iron was the material best adapted to resist compression. He could not agree with the remark that it was not necessary to combine the qualities of the girder with the rib. A cast-iron or wrought-iron arch differed from one of stone, in that there was less depth of material, usually, between the extrados and the intrados, and in order to make the iron act properly, under unequal distributions of load, it was necessary to give it a greater or less degree of stiffness. To get the requisite amount of stiffness in

the rib, a considerable addition must, by the introduction of flanges, be made to the amount of material that was required merely to resist the compression that came upon that rib as an arch. In fact, in that way, the qualities of a stiffening girder must be combined with those of an arch in the rib itself, to produce a sufficiently stiff rib. He agreed with the remarks which had been made, as to the inutility of unduly strengthening the horizontal member, for the purpose of assisting the arched ribs, or for employing that member further than was necessary for obtaining the requisite stiffness in the spandrils.

Mr. J. Taylor thought there was a tendency to depreciate the use of cast iron for bridges. No doubt the employment of wrought iron was advantageous where the span was large and the conditions of water-way stringent; but where a stream could be crossed by openings of moderate span, and where the conditions as to the water-way were not stringent, there was great advantage in the use of cast iron. He believed it could be used on an average at about one quarter less cost than wrought iron. He thought another important consideration was the comparative durability of the two materials. Cast-iron bridges were in existence that had been erected one hundred years; but there had not been the same lengthened experience with wrought-iron bridges; and it was known that the decay of wrought iron was very rapid, unless it was carefully watched and attended to. With regard to the two bridges under discussion, he thought that ribs of cast iron would have been better mechanically than ribs of wrought iron.

Mr. W. H. Barlow was not prepared to recommend the use of cast iron, in structures of this description, unreservedly; the material seemed rather dependent on the magnitude of the bridge; and if it was a very large structure, he did not see how cast iron was to be used advantageously. It was pointed out with regard to the cast-iron railway bridge over the River Severn, that an arch of cast iron was obliged to have a certain amount of wrought iron in the top to give it stiffness; but if the arch was of wrought iron, there would be stiffness both in the arch itself, and in the member above the arch; and in his own practice he had found it beneficial to employ wrought iron in that manner. With regard to these particular bridges, he would remark that one of the advantages of the employment of wrought iron appeared to have been lost sight of, viz., each arch was made detached from its neighbour: stone was put in between them, and a complicated arrangement rendered necessary by the introduction of the stone. If the whole had been made continuous of wrought iron, there would have been a more complete combination of the parts, and greater stiffness over the haunches, as well as greater strength in the material. At the same time he considered the Victoria Bridge to be one of the

most elegant structures that had been carried across the River Thames.

Mr. J. Fogerty, having had charge of the construction of the bridge over the River Severn at Coalbrookdale, stated that the cost of the cast iron was only £8 10*s.* per ton, and that of the wrought iron £14 per ton; and that the total cost of the bridge was a little over £11,000. In consequence of being obliged to make a separate pattern for every segment of the rib of the arch, he did not think a cast-iron bridge could be made with such expedition as a bridge of wrought iron, although he agreed that cast iron was the proper material for an arch; and probably that circumstance might have influenced Mr. Fowler in using wrought iron for the Victoria Bridge, which had to be finished within a limited time. The latter was erected in a little over twelve months, whereas the bridge over the River Severn was nearly two years in construction. It might have been completed in less time, but there was always a much greater amount of fitting and variety of parts in cast-iron structures. A slight difficulty was experienced in casting some of the segments of the arch of the Severn Bridge. The heel segment castings each weighed about 13 tons, including the heel or circular end, and the difficulty experienced was that the hydraulic pressure of the molten iron when rising upward in the large projecting end of the segment was so great as, in some instances, to blow up the flat portion of the casting. He recommended that such castings should be in detached pieces, and connected together with flanges. These castings were made at the Coalbrookdale Company's works; and he believed three or four of the first were bad castings, and one blew up altogether in consequence of the objectionable construction alluded to. He submitted there was no need for the ribs being circular at the springing ends, as there was no movement whatever at the springing of the arch. Two bridges of this description had been constructed over the River Severn and severely loaded, but in neither instance could the slightest movement be detected. A great deal of money was expended in fitting these semicircular castings to the springers, but he thought it would have been just as well for the springing to rise from a plane surface.[1]

Mr. J. H. Lloyd would be glad to hear whether this bridge was really to be considered as a girder bridge or an arch bridge? Whether there was, in fact, any effect from what was called the girder, or whether the whole effect was not due to the arch?

Mr. Vignoles was old enough to recollect two or three fluctuations in the opinions of engineers as to the relative merits of cast iron and of wrought iron for bridges. The bridge over the Severn reminded him of one of the best lessons he ever got from his grand-

[1] For details of this bridge, *vide* "Engineering," vol. i., p. 367.

father in engineering—now sixty years ago—in reference to a design which he could fancy was identical with that bridge. The subject was brought prominently forward on the occasion of the destruction of the cast-iron bridge at Chester, when the question of the introduction of wrought iron instead of cast iron was discussed. He was inclined to agree that, on the whole, the change from the iron arch to the girder was merely the transference of the same materials into another form. No doubt it was more economical, more expeditious, and more advisable to use wrought iron in bridges of large spans, but it was the reverse for bridges of ordinary span. In his opinion, there was nothing to account for the prejudice and antipathy against the adoption of cast iron for railway structures but the many accidents that had occurred fifteen or twenty years ago; and, in fact, cast iron for bridges under 200 feet span was as eligible as wrought iron, provided equal care was bestowed upon it.

Sir Charles Fox, in reply upon the discussion for his son, who had been unexpectedly summoned to Canada, stated that he not only desired, but made a request that the important question should be discussed, as to whether the arches of bridges of this kind should be constructed of cast iron or of wrought iron. His own opinion was that they should be of cast iron, but in this particular case they were governed by a variety of circumstances, one of which was that the then existing bridge, up to which they had to join, had wrought-iron ribs. He had been styled a "cast-iron man," because he advocated its use wherever it was possible; but it should be remembered, in the first place, that cast iron was cheaper, and, in the second place, that it was more durable than wrought iron. If he had to construct this bridge again, without any conditions connected with the joining to another bridge, he would make the ribs of cast iron, of such strength that the varying line of thrust should always be within the rib itself. He thought engineers had gone astray in the use of wrought iron in various structures, because he was sure that cast iron, if properly prepared and proved before it was put in place, was as safe as wrought iron. He had always taken care that every piece of metal on which safety depended should be proved on the spot immediately before it was put into place. In the case of the girders for the Exhibition Building of 1851, against which so much was said, he believed the reason why they did not fail was that every girder was put into a hydraulic press and proved the moment before it was required; and, as it was more important to record failures than successes, he would state that a number of girders broke in the proof, and were put on one side.

He saw no difficulty in making a bridge of this span of cast iron. There was an example in Southwark Bridge, erected years ago, and it must be admitted that it had stood its ground. The constructor

of that bridge made no abstruse calculations as to whether the top girder or the spandrils were to add to its strength. He made the cast-iron ribs sufficiently strong, and there it stood a monument to Rennie, and one of the finest structures of that day.

Assuming the ribs to be of cast iron, he would make the top a continuous girder, only sufficiently strong to carry the superincumbent load. He admitted that, in this bridge, the top girder was stronger than was necessary, and he thought a considerable saving might have been effected in it, by putting corresponding strength in the arch, and making it of cast iron. He would, however, use wrought iron for the longitudinal girders for this reason:—He had ascertained, by a number of experiments, that the variations in the length of a wrought-iron girder, due to alternations of temperature in this climate, could be accommodated within the limit of elasticity of the girder itself; but that was not the case with cast iron. When the reservoir of the New River Company in the Hampstead Road was removed, many of the pipes leading to it, being of cast iron and flanged together, were found broken in two, in consequence of their inability to expand and contract. This proved that the limit of elasticity in cast iron was not sufficient to allow the metal to make the necessary accommodation, whereas wrought iron undoubtedly possessed that quality. Those accustomed to railway works knew that when rails were laid down in the middle of winter, it was a common practice for the platelayers to put a penny-piece between the two rails, to allow for the expansion of the metal in the summer. If a bar of wrought iron 15 feet long was compressed $\frac{1}{4}$ inch in the direction of its length, for the first time a small permanent set would take place, but it might subsequently be compressed a hundred times without that set being increased, provided the pressure was not greater than at first. Many years ago it was considered, in proving an iron structure, that if it took a permanent set it was damaged; but from a number of experiments he had come to the conclusion that all structures, the first time they were loaded, did take a permanent set. Some years ago he took a contract for the supply of chains for a suspension bridge; and in the specification it was stated that any link that took a permanent set should be rejected. He made a proving-press for the purpose, and found the first time any bar was stretched it took a permanent set. An engineer once said to him, "If your structures take a permanent set, I will reject them." His reply was, "Then you will reject them all, for they all do that." Therefore he had to ascertain what was the permanent set due to the first operation of proof. Another engineer said, "If any bar take a permanent set in my presence, I will reject it." He replied, "Very well: your proof is 10 tons per sectional inch: I will put it into the press and prove it to 11 tons, the day before you come, and take the stretch

out of it; and with 10 tons you will have no permanent set." It was found on trial that a 12-feet bar put to that proof took a permanent set of $\frac{1}{40}$ inch; and it was accordingly agreed that a bar, not taking a greater permanent set than that, should be considered good. As a wrought-iron girder, when proved for the first time, would take a permanent set, it was desirable to ascertain exactly what that would amount to, and having ascertained that, the iron might be considered in a normal state; and provided a greater load were not put on, there would be no further alteration. Under these circumstances he would make the longitudinal girder of wrought iron, but only strong enough to carry the load.

He did not admit that these upright or diagonal spandrils were of much value. He thought the rib should be of cast iron, of sufficient strength in the top and bottom flange, that either flange might take the thrust of the arch under any altered position of the strain. He did not see any necessity for the horizontal girder having expansion joints over each pier, inasmuch as the total difference due to expansion and contraction was within the limits of elasticity of the material. Moreover, there was this fact with reference to the expansion joints of the original bridge, that from the autumn of the year 1865, to the spring of the year 1867, these joints had been carefully watched, and during that period, although there had been great alterations of temperature, they never moved a hair's breadth, and even the rust between one part and the other had not been broken. Therefore he did not see any advantage in going to the expense of these expansion joints when, in fact, there was no expansion.

As to the piers, he considered that, in structures of this kind, they ought to be regarded as vertical props, having no lateral stability. Engineers might be called upon to build a pier 100 feet high, and who could say that such a pier would not easily move? He remembered during the construction of the London and Birmingham Railway, it was proposed to erect a tall pier of brickwork, 6 feet square, and 20 feet high, to receive a transit instrument, for setting out the centre line of the Watford Tunnel. He believed it could be done equally well with an ordinary theodolite; and the result was that, before the transit instrument was fixed in its place, the tunnel was set out, the shafts sunk, and a heading driven from end to end. If, on looking through the transit instrument, when placed on the brick-pier, he gave the pier but a touch with the hand, so great was the motion produced, as to render any useful observation very difficult.

Then, as to the question of the cheapest way of making a pier, he believed it to be, as in this case, by cast-iron cylinders. If it had not been for the masonry in the existing bridge, with which a junction had to be effected, they would have brought the cylinders

up to the springing. The Act required the foundations to be carried down to a certain depth below the bed of the River Thames, to allow the Conservators, if and when they thought fit, to dredge out the bed to a greater depth: he had, therefore, to sink below the foundations of the old bridge. If he had put in a coffer-dam for the excavation he might have dislodged the clay from under the old pier; therefore he put in cylinders to render that contingency impossible, and the result was, a pier which answered well and cost less money.

As to the variation of strains brought upon different parts of these two structures, the Government Inspector, on testing them, found the deflection nearly equal, and consequently the strains also must be nearly the same. In the two bridges, at Barnes and Richmond, to which reference had been made, and the ironwork of both of which he was permitted to construct, the arches were of cast iron. The Barnes Bridge was of three arches, each of 120 feet span, and the Richmond Bridge of 100 feet span. Both bridges had well answered their purpose; and, in fact, he had never heard a complaint of them.

It only remained for him to add, that the works at Battersea, which had cost £920,000, had been completed within $1\frac{1}{4}$ per cent. of the original estimates.

Mr. Wilson, in reply, said, in reference to the choice of wrought iron for the Victoria Bridge, that it was now so long since it was designed, he had almost forgotten the precise reasons which guided that choice; but he thought the chief inducements for adopting wrought iron, were economy in cost and facility and quickness of construction. A gantry was erected over the river, for the purpose of setting the masonry of the piers, and it was found that it would be sufficiently strong to erect wrought-iron arches: whereas to have erected cast-iron arches would have involved a large additional expenditure, as a much stronger centering would have been requisite. There were 80 inches of sectional area of wrought iron in the arched rib, and for the same cost only, 160 inches of cast iron could have been obtained, which would have been insufficient; although, had it been otherwise, he should have preferred the latter, as there could be no doubt that thin plates of wrought iron must be more subject to deterioration from vibration and corrosion, and an arch of cast iron of sufficient section must have a longer life. The two chief points of difference between the original bridge and the widening occurred in the foundations of the intermediate piers, and in the distribution of metal in the superstructure. With reference to the piers he had but little to say. He knew that certain difficulties occurred, which made it almost impossible to continue the original plan, although he would have preferred doing so; because a pier of solid masonry

was more substantial, and certainly more reliable, than one built of two different materials. But he did not think the ability of the pier to resist the horizontal strain was in any way affected by the change; for the weakest part of the pier occurred above the low-water line, at a point considerably above the foundations, where the two were precisely similar in construction and sectional area. With respect to the superstructure, the differences were very great, and clearly showed that the two works had been calculated on totally different principles. In designing the original bridge, the calculations were all based upon the assumption that the piers were of sufficient stability to resist the maximum horizontal thrust that would come upon them; and, of course, having the piers to design with the other parts of the viaduct, the attention of the Engineer was specially directed to that object, and the greatest care was taken to ensure its being effected. He would not have alluded further to this, had it not been so specially referred to during the discussion; but as there seemed to be some doubt on the subject, he would make a few remarks, with a view to prove the statement he had made.

Assuming a load of sufficient amount to be applied to the pier, it would be found that fractures would occur at two points. The resistance to the upper fracture would be the tensile strength of the spandril-bars, holding down, by means of the horizontal girder, the upper portion of the pier to the arched rib; and the resistance to the lower fracture would be governed by the power of the masonry to resist the crushing at the arris.

In estimating the amount of resistance in a pier of this bridge, it was found that, if one arch was loaded and the other light, the unbalanced thrust was that due to the rolling load, and equal to 2,734 cwt. Of that amount, the upper portion of the pier would transmit 480 cwt. to the spandril-filling. In the same manner, the spandril-bars would transmit 280 cwt.; so that a total horizontal thrust of 760 cwt. would be transmitted, leaving 1,974 cwt. to be opposed by the lower portion of the pier.

Plotting the line of pressure, corresponding to this horizontal thrust, and the loads occurring at the different sections, the weakest point was found to be at **A—B** (Plate 8, fig. 2), where the centre of pressure was 4 feet from the axis of the pier, the weight above being 50 cwt. per square foot, and the thickness of the pier at that point being 15 feet. The moment of resistance of the section would be 450, whilst the bending moment would be 36,000 cwt., with a strain of 80 cwt., giving a total maximum compression on any part of the brickwork of 130 cwt. per square foot, or $2\frac{1}{2}$ times the mean pressure. Thus it would be seen the centre of the pressure, where the point of greatest weakness was, fell 4 feet from the axis of the pier, and that was at a point where the weight would give 50 cwt. per superficial foot. He knew of no reliable experiments, with

regard to the elastic power of brick or stone work in resisting compression; but from the best data, it was calculated that the deflection of any one of those piers would not exceed $\frac{1}{8}$ inch, and that this could only result from a load of $1\frac{1}{4}$ ton per lineal foot on both lines of the railway, exactly fitting the span, without any part projecting over the arch. This could not occur in practice; therefore, the least possible maximum strain had been considered, and credit taken for all the advantages it gave. The arches, springing from fixed abutments, had been designed to act independent of one another; but, of course, credit was taken for the natural stiffness of the spandrils, and each arch was calculated to resist the greatest pressure resulting from one arch being loaded and the adjoining arch being light. The span of the arch was 175 feet; the rise 17 feet 6 inches, and the sectional area 80 inches. The calculated dead load was $12\frac{1}{2}$ cwt., and the rolling load also $12\frac{1}{2}$ cwt. per lineal foot: therefore the maximum thrust due both to the rolling load and to the fixed load was 2,734 cwt., and the compression per square inch at the centre, 68 cwt., while the strains at the springing, calculated in the ratio of that at the crown, would be 74 cwt.

Owing to the difficulty of ascertaining the relative degrees of stiffness in different parts of an arch of that character, it was almost impossible to determine the precise condition of the load on which the maximum bending moment would obtain; but it was assumed to take place when $\frac{6}{10}$ths of the arch were fully covered by the rolling load.

The effect of that load was indicated in Plate 8, fig. 1, which showed the line of thrust upon the arch. Assuming it to be unconnected with the horizontal girder and spandril-fillings, the greatest strain would be at the haunch, where the compression was 5 tons on the upper table, and 0·32 of a ton on the lower, the same being reversed on the opposite side. This showed that the line of pressure was kept within the arch; in fact, it was 0·2 of a foot within the flange. The result of this would be to reduce the strain of 5 tons, to 4 tons per square inch, by the additional strength imparted to the rib by the horizontal girder and spandril-filling. These strains would, of course, be further influenced by changes of temperature, tending to increase them. The observed range of expansion, in iron structures in this climate, being $\frac{1}{2}$ inch per 100 feet, the span of 175 feet would give an expansion of $\frac{7}{16}$ inch, producing a rise and fall at the crown, and an additional strain of $12\frac{1}{2}$ cwt. per inch, at the crown and springing. At a point in the haunch, where the maximum bending moment occurred, it would be 10 cwt., which, added to the strains already deduced from the most disadvantageous position of the rolling load, would give 90 cwt. as the greatest amount of compression that could occur on a rib of

Fig: 1.

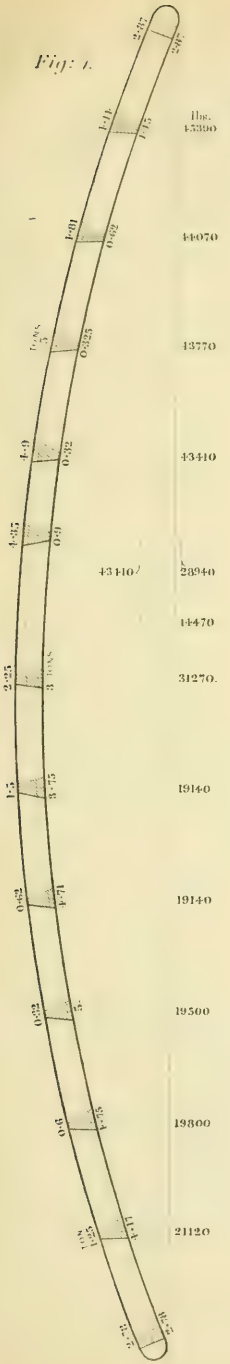


Fig: 2.

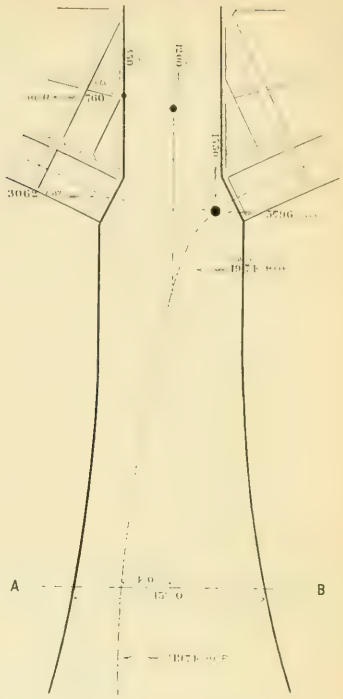
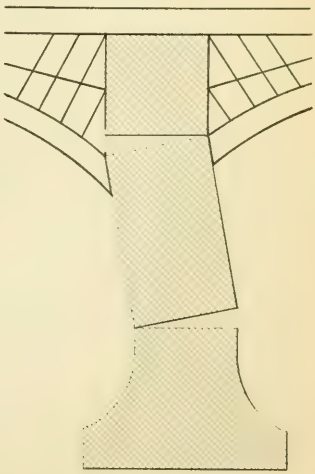


Fig: 3.



these dimensions, under the worst combination of circumstances—unfavourable distribution of load, and extreme temperature.

Allusion had been made to the expansion joint, and the segmental shoes to the ribs. The former was of little importance; it acted as a telescopic joint, giving stiffness and continuity, with freedom for expansion; and the chief object of the India-rubber washers was to get rid of any jarring motion that might take place. The latter afforded facilities in the erection of the bridge, by bringing the ribs to a bearing, and ensuring perfect equality of compression throughout the whole sectional area of the rib; and when once fixed in place and adjusted to its bearings, it would become a rusted journal of 3 feet 6 inches diameter, and unless the line of pressure fell without the flange, no movement could take place in the shoe; in other respects it came practically under the same conditions as a square end.

Some explanation was required respecting the relative cost of the two works. He had stated in his Paper, that the total cost of the original bridge was £84,000, which was equal to £2 13*s.* per superficial foot. As that appeared to be the precise cost, per superficial foot, of the widened work, he was startled with the similarity, as he thought there ought to have been a considerable difference; but it was accounted for, in some degree, by the circumstance that there was a large expenditure in the original bridge, in the face-work, and cut-water, and parapet railing, which was saved in the construction of the widening, which had only one face, and that was composed of the stone and iron-work from the original bridge, removed and re-set. Deducting £13,000 for this, it would reduce the cost of the original bridge, for the purpose of comparison, to £2 4*s.* per superficial foot, as against £2 13*s.*, the cost of the widening.

Sir Charles Fox begged to say one word with reference to the curved ends of the ribs: the only use of them was in fixing; when the skewbacks were in place, no further benefit was gained from them. It appeared to him that, if any motion were deemed desirable, it would be better to make the bearing faces of the skewback castings plane, and the ends of the girders very slightly curved, as in the case of the cast-iron bridge carrying the railway over Fairfield Street, in Manchester, where he had curved the ends of the ribs about $\frac{1}{10}$ inch, to allow a slight rolling motion, but in his opinion, the best way was to make both planes, and having bolted the skewbacks to the ribs, and fixed both in place, then to bed and back up the skewbacks with brickwork, or masonry set in cement, so as to secure them accurately in their proper places. That, in his opinion, was the cheapest and best mode of making sure that the ribs of an arch were accurately thrusting against the skewbacks.

December 10, 1867.

CHARLES HUTTON GREGORY, Vice-President,
in the Chair.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye Laws, as Students of the Institution:—Charles Benjamin Braham, Frank Samuel Braham, Charles Capel Clutterbuck, George Selwyn Edwards, Thomas Archibald Fisher Hall, Josiah Harding, and William Walton Williams, jun.

The discussion upon the two Papers, "On the Victoria Bridge," by Mr. W. Wilson, and "On New Railways at Battersea," by Mr. C. D. Fox, was continued throughout the evening.

ANNUAL GENERAL MEETING.

December 17, 1867.

JOHN FOWLER, President,

in the Chair.

Messrs. C. Frewer, H. Hayter, F. M'Clean, T. M. Smith, and Jos. Taylor, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council; and it was resolved that the ballot papers should be sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The list of members prepared for Council, together with the record of the attendances of the Members of Council, in Council and at the Ordinary General Meetings, was read, and the Ballot was declared open.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Geo. P. Bidder, jun., and J. D. Baldry, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. J. D. Baldry and C. E. Hollingsworth be requested to undertake the office of Auditors for the ensuing year.

Mr. Bidder, jun., returned thanks.

The Telford and Watt Medals, and the Telford and Manby Premiums of Books, which had been awarded, were presented.

Resolved,—That the special thanks of the Meeting be tendered to Mr. W. H. Barlow, F.R.S., M. Inst. C.E., for his Paper, "Description of the Clifton Suspension Bridge."

Mr. Barlow returned thanks.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Gregory, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Fowler, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Fowler, President, returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

CHARLES HUTTON GREGORY.

Vice-Presidents.

Joseph Cubitt.	Thomas Hawksley.
Thomas Elliot Harrison.	Charles Vignoles, F.R.S.

Other Members of Council.

Members.

James Abernethy.	Frederick Joseph Bramwell.
William Henry Barlow, F.R.S.	James Brunlees.
John Frederic Bateman, F.R.S.	George Willoughby Hemans.
Joseph William Bazalgette.	John Murray.
Nathaniel Beardmore.	George Robert Stephenson.

Associates.

John Horatio Lloyd.	Captain Henry Whatley Tyler.

Resolved,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their ever-ready, cheerful, and valuable services to the Institution.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hayter, F. M'Clean, T. M. Smith, and Jos. Taylor, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the ballot-papers be destroyed.

ANNUAL REPORT.

Session 1867-68.

The Council of the Institution who were elected at the last Annual General Meeting, in resigning their trust, have now to report upon the matters which have engaged attention during their year of office.

It is a source of gratification to the Council, that the interest taken in the Ordinary General Meetings by the members of all classes continues to increase. It will be remembered that a principal, if not the primary, motive, which led to the establishment of the Institution was to afford an opportunity for the free and mutual interchange of individual observation and experience in the various branches of engineering. This object has been steadily kept in view during the fifty years which have elapsed since the foundation of the Society, and it is satisfactory to observe, that the value and importance of the Original Communications, and of the discussions, have been fully maintained.

A brief enumeration of the subjects which have been brought forward at these Meetings during the past Session, and the recollection of the remarks which they elicited, will corroborate these statements. The topics dealt with have related to the Employment of Steam Power on Canals; to the Smelting of Copper Ores; to the Construction of Light Railways for branch lines and comparatively poor districts of country; to Inter-communication in Railway Trains; to Ships of War; to Suspension Bridges of Great Span, and the means by which such structures may be rendered available for the passage of railway trains; to Steep Gradients and Sharp Curves on Railways, particularly in reference to possible plans to be adopted for overcoming mountain passes, and other similar barriers to the modern system of communication; to the River Tyne; to the Suez Canal; to the Optical Apparatus of Lighthouses; and to the Filtration of Water.

For some of these communications the following Telford and Watt Medals, and Telford and Manby Premiums of Books have been awarded:—

1. A Telford Medal, and a Telford Premium, in Books, to James T. Chance, M.A., Assoc. Inst. C.E., for his Paper "On Optical Apparatus used in Lighthouses."

2. A Telford Medal, and a Telford Premium, in Books, to Edward Byrne, M. Inst. C.E., for his Paper, "Experiments on the Removal of Organic and Inorganic Substances in Water."
3. A Telford Medal, to George Biddell Airy, Astronomer Royal, Hon. M. Inst. C.E., for his Paper "On the Use of the Suspension Bridge with Stiffened Roadway for Railway and other Bridges of Great Span."
*4. A Watt Medal to Colonel Sir William Thomas Denison, K.C.B., R.E., Assoc. Inst. C.E., for his Paper on "The Suez Canal."
5. A Watt Medal, and a Telford Premium, in Books, to John Bourne, for his Paper on "Ships of War."
*6. A Telford Premium, in Books, to Captain Henry Whatley Tyler, Assoc. Inst. C.E., for his Paper "On the Working of Steep Gradients and Sharp Curves on Railways."
*7. A Telford Premium, in Books, to William Henry Preece, Assoc. Inst. C.E., for his Paper "On the Best Means of Communicating between the Passengers, Guards, and Drivers of Trains in Motion."
*8. A Telford Premium, in Books, to William Alexander Brooks, M. Inst. C.E., for his Paper on "The River Tyne."
9. The Manby Premium, in Books, to Charles Douglas Fox, M. Inst. C.E., for his Paper "On Light Railways in Norway, India, and Queensland."

Mr. W. H. Barlow's description of "The Clifton Suspension Bridge" was not taken into consideration in the award of Premiums, in accordance with custom, the Author being a Member of Council; but the thanks of the Institution are eminently due to Mr. Barlow for his valuable communication, and for the suggestions he made in regard to the materials to be employed and the principles to be adopted in bridging wide spans, which led to so useful and practical a discussion.

The record of these Papers and discussions is contained in Volume XXVI. of the Minutes of Proceedings for the Session 1866-67, which has been forwarded to the members in a complete form, in accordance with the general wish which has been expressed in favour of an annual volume rather than separate parts.

The publications of the Institution are at present limited to the printing of the Papers that are read, and the reports of the discussions which take place upon them; but the members of all classes have been invited to contribute short notes, not necessarily for reading at the Meetings, giving the details and results of any experiments or observations on subjects connected with engineering science or practice, for the purpose of forming an Appendix to the

* Have previously received Telford Medals.

Minutes of Proceedings. If these contributions were given, a mass of most useful information might be collected and put on record, at comparatively little trouble to each individual member, where it would always be accessible; and such facts, so gathered together, would serve as practical illustrations in elucidating particular points in the theory and practice of engineering.

The Council have to report that many circumstances, beyond their control, have prevented a satisfactory conclusion being arrived at as to the plans that ought to be adopted for providing additional accommodation for carrying on the business of the Institution. They are, however, fully aware of the growing importance of the subject, in view of the large increase in the number of members and of the formation of the new class of Students, as well as of the fuller attendance at the Meetings, and they trust that it will receive the early consideration of the new Council.

The Council having further considered the proposal for the establishment of a Junior Class in the Institution, as mentioned in the last Annual Report, it was decided to recommend to a General Meeting of Members to extinguish the existing Graduate Class, and to create, in lieu thereof, a class of Students, to be admitted, and remain attached to the Institution, during the pleasure of the Council. To give effect to this determination, certain alterations in and additions to the Bye-laws became necessary. The suggested alterations, having been revised by the Solicitor, were set forth in a circular convening a General Meeting of Members for the 26th of June, 1867, and after discussion they were, with some modifications, adopted.

The rules, as sanctioned, prescribe that "Students shall be persons not under eighteen years of age, who are, or have been, pupils of Members or Associates of the Institution, and who have the object or intention of becoming Civil Engineers; and such persons may continue Students until they attain the age of twenty-six years, but not longer."

The mode of admission of Students, and the privileges to be enjoyed by them, are thus set forth in the Rules:—

"SECTION IV.

"ADMISSION OF STUDENTS.

"1. Students may be admitted by the Council on the recommendation (according to Form A 2 in the Appendix) of the Member or Associate under whom they are, or have been, pupils; and they may remain Students of the Institution, at and during the pleasure of the Council, until they attain the age of twenty-six years, when they shall cease to be Students.

"2. Any person admitted into the Institution as a Student shall be informed thereof by letter (according to the Form E 1 in the Appendix), stating that the first year's subscription must be paid within two months, otherwise the admission will be void, when he shall be entitled to attend the Ordinary General Meetings, but not to vote at such Meetings, and to have the use of the Library, but subject to such regulations as the Council may, from time to time, prescribe, as well as to receive a copy of the Minutes of Proceedings relating to each Session during which he shall continue to be a Student.

"3. Students of the Institution are eligible to compete for the premiums or prizes arising out of the 'Miller Fund,' and any other funds appropriated by the Institution, or any person or persons, for premiums or prizes for Students.

"4. The Council may accord to Students other privileges, but subject to such terms, regulations, and restrictions as they shall from time to time prescribe.

"5. No Student will be allowed to introduce a stranger into the rooms of the Institution."

With regard to the Contribution to the Funds, it was resolved that "Each resident Student shall pay two guineas, and each non-resident Student one guinea and a half per annum." Students are not liable for any fees or subscriptions other than the annual contribution just named.

Although not specifically mentioned in the Rules, it was intimated to intending candidates for admission into this new Class, that it was contemplated to grant, under the control of the Council, the use of the theatre of the Institution to the Students, for supplemental Meetings, for the reading and discussion of Papers among themselves, and possibly, also, for the delivery to them of lectures upon special subjects, the object of such supplemental Meetings being understood to be for the advancement in scientific and technical knowledge of the junior members of the profession. As seventy-eight Students have already been admitted, and as the number is likely to be still further increased, it is to be hoped that the succeeding Council will, as soon as possible after their election, make such arrangements as they may deem advisable to carry out the spirit of this understanding.

It may be mentioned that the few Graduates remaining on the books, at the date of the last Report, have been transferred either to the class of Members or to that of Associates, so that the class of Graduates has now no existence in the Institution.

The Council think it right to report, though not yet in a position to express any decided opinion upon the questions thus raised, that they have received several important suggestions, having in

view the increase of the usefulness of the Institution, particularly to the junior members of the profession. Among these may be named, a proposal to aid in some way in the publication of a series of standard professional text books; another advocating the establishment of Readerships in the Institution, and also that a systematic inquiry should be instituted into the state of the scientific and technical education of Engineers in France and in Germany; and another, suggesting that some form of endowment is necessary, to give vitality to the systems of preliminary education at present pursued by some youths who are destined subsequently to enter an Engineer's office or factory.

These are matters that will require grave deliberation before any decision can be arrived at; and they are now only mentioned in order to show the growing feeling that the Institution, as the representative body of the Engineering profession, should extend its sphere of operations, so as to meet the requirements of the present day.

Having understood that it was in contemplation, by a body of gentlemen associated under the style of the "Society of Engineers," to apply for a Royal Charter of Incorporation, and thinking it possible that similar applications might be made by other Societies, the Council deemed it proper, in the interests of the profession and of the Institution, to request permission to be allowed an opportunity of laying before H. M. Privy Council, such objections as it might appear to them fair to raise, in the first place against the grant of a second Charter to the same profession, especially to a metropolitan Society dealing, or proposing to deal, with precisely the same subjects; and in the next place, should it be decided to submit any such Charter for the approval of H. M. in Council, then to the Bye-laws and details of such Charter, as well as to the name of the Society proposed to be incorporated.

When it was officially ascertained that a Petition had been addressed to the Queen in Council, for the grant of a Charter of Incorporation to a "Society of Engineers," although the contents of the petition were not of course disclosed, and the grounds upon which the application was based were not known, the Council, acting under the advice of their Solicitor, determined to proceed in a similar manner, and to petition the Queen in Council against making such a grant. The following is a copy of the Petition—

"TO THE QUEEN'S MOST EXCELLENT MAJESTY IN COUNCIL.

"The Humble Petition of THE INSTITUTION OF CIVIL ENGINEERS,

"HUMBLY SHEWETH,

"That the Institution of Civil Engineers was originally established in the year 1818, and by a Charter granted by His late Majesty King George the Fourth, and dated the 3rd day of June, in the ninth year of his reign (being

the year of Our Lord, 1828), after reciting among other things that Thomas Telford, Esquire, a Fellow of the Royal Societies of London and Edinburgh, and others, had formed themselves into a Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constituted the profession of a Civil Engineer, being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in States, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power for the purposes of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns; His said Majesty did will, grant, and declare that the said Thomas Telford and such others as had formed themselves into and were then members of the said Society, or who should at any time thereafter become members thereof according to such regulations or bye-laws as should be thereafter framed or enacted, should, by virtue thereof, be the members of and form one body Politic and Corporate for the purposes aforesaid by the name of 'The Institution of Civil Engineers,' by which name they should have perpetual succession and a common seal, and by the same name to sue and be sued, implead and be impleaded, answer and be answered unto, in every Court of His said Majesty, his heirs and successors.

"That the Institution of Civil Engineers has been recognised ever since its first establishment, and more particularly since the granting of the said Charter, by the British Government and by the Houses of Parliament, and also by foreign powers, as the representative body of the engineering profession in the United Kingdom.

"That your Petitioners have been informed and believe that a Petition has been presented to your Majesty, praying that a Charter of Incorporation may be granted to a Society calling itself 'Society of Engineers.'

"That your Petitioners have also been informed and believe that such new Society was first established in the month of May, 1854.

"That, according to the original constitution of this new Society, it was not necessary that the members of it should be engineers or connected with engineering pursuits; and, according to its rules and bye-laws, published so lately as the year 1866, it was established for the discussion of scientific and other subjects of general interest; but in the present year, 1867, the professed object has been altered, and it is now stated to be established for the advancement of engineering science and practice.

"That the said Society holds its meetings at the Lower Hall, Exeter Hall, Strand.

"That your Petitioners feel convinced that the title of 'Society of Engineers,' adopted by this Society, has already had the effect of misleading the public, and has led to the supposition that The Institution of Civil Engineers and the Society of Engineers were one and the same body, and has given to this new Society the appearance of being connected with your Petitioners' Institution, and has also given it a footing and standing or position with the scientific world which it would not otherwise possess; and should a Charter be granted to it, these evil consequences to your Petitioners would be augmented to a very great extent, and would be of a very serious character.

"That should a Royal Charter of Incorporation be granted by Your Majesty to this new Society, by the name of 'Society of Engineers,' great mistakes and confusion would undoubtedly arise in many respects, in consequence of the similarity of the name of your Petitioners of 'The Institution of Civil Engineers,' and the name proposed to be adopted by this new Society of 'Society of Engineers,' in the following among other instances: references contained in

Acts of Parliament, in parliamentary and other agreements, contracts, references from foreign governments, and with reference to legacies which may be intended to be left to your Petitioners' Institution.

"Your Petitioners humbly submit that it is not usual and not expedient to grant Charters of Incorporation to two different bodies having the same or similar names, or intended or apparently intended for the same or similar objects and purposes, and more particularly when such two bodies have their places of meeting and may be said to exist in the same city or town.

"That your Petitioners humbly submit that no other Charter of Incorporation should be granted by your Majesty to any body or Society professing to be a Society of Engineers, or proposing to take as part of its name or title any reference to engineers or engineering, or having a title or name similar to the title or name of your Petitioners.

"Wherefore your Petitioners humbly pray that your Majesty will be graciously pleased not to grant a Charter of Incorporation to the said Society called 'Society of Engineers;' or that if your Majesty shall be graciously pleased to grant the said Society a Charter of Incorporation, then that the corporate name of the said Society shall not contain the word 'Engineers,' or any word having reference to engineers or engineering.

"And your Petitioners, as in duty bound, will ever pray."

Subsequently, a deputation from the Council was received by H. G. the Duke of Richmond, the President of the Board of Trade, to which department the question had been referred for consideration and report, and had thus an opportunity of fully explaining the views unanimously entertained by the Council. Ultimately, after the matter had been duly considered by the Lords of H. M.'s Council, their Lordships informed the "Society of Engineers," that they could not recommend the grant of a Royal Charter of Incorporation to that Society, under a name which was liable to be confused with that of "The Institution of Civil Engineers."

The Council would take this opportunity of reminding the members, that it has never been sought to make this body an exclusive one, or to restrict its privileges to any one class or branch of the profession; but that all Engineers have been, and are, cheerfully received into the respective classes for which, under the Charter and Bye-laws, they may be qualified.

Her Majesty's Commissioners for the Paris Universal Exhibition of 1867, of which your President, Mr. Fowler, was one, having requested the Council to furnish the names of two or three gentlemen to serve as Jurors in the Classes of Civil Engineering and Machinery, Mr. Charles Hutton Gregory, Vice-President, Mr. George Willoughby Hemans, Member of Council, and Lord Richard Grosvenor, M.P., Associate of Council, were nominated, and acted in that capacity, rendering much valuable assistance, in matters connected with the duties so undertaken.

Every effort has been made to preserve the efficiency of the

Library. At the suggestion of several Members, who devoted much time and trouble to the inquiry, considerable purchases have been made of the higher class of mathematical works, both of English and of foreign authors. These, it is to be hoped, will prove of service to the younger members, particularly in view of the tendency of the present day to develop the more recondite elements of the theory of Engineering, and to place it on a more scientific basis than has hitherto been attempted. Other purchases of periodical French and German engineering literature contain much valuable information, and afford incontestable evidence of the rapid strides made by the profession on the Continent of Europe of late years.

The numerous additions to the Library, by presentation and by purchase, will soon render it desirable to issue a Supplement to the Catalogue, although printed so recently as the close of the year 1865. In the meantime the new works, as received, are entered in a MS. Catalogue, so as to be readily accessible.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes, during the years 1865-66, and 1866-67 (taking into consideration the names which have been erased from the Register), is as follows:—

Year.	Honorary Members.	Members.	Associates.	Graduates.	
1865–66.					
Transferred to Members	..	..	12	..	
Elections	1	53	109	..	163 − 27 = 136
Deceases	1	11	12	..	27
Resignations	..	..	3	..	
1866–67.					
Transferred to Members	..	..	11	4	
Ditto Associates	..	..	..	2	
Elections	..	48	79	..	127 − 33 = 94
Deceases	2	14	10	..	33
Resignations	..	1	2	..	
Erased from Register	..	..	3	1	
Members of all Classes on the Books, November 30, 1867	18	589	826	..	1,433

In this calculation the Students, as not being members of the Corporation, but only attached to the Institution, are excluded. It will be observed that the actual effective increase during the past Session has been 94, or at the rate of 7·02 per cent. on the present

number of members of all classes. The gross numbers, at intervals of five years, for the last quarter of a century, commencing on the 30th of November, 1842, are 525, 610, 745, 835, 1,000, and 1,433, showing an increase in each quinquennial period of 85, 135, 90, 165, and 433 in that just closed.

The following Member and Associates have tendered their resignation, and have been permitted to retire from the Institution: Alfred Burges, Member; Elijah Hoole, and Major John Charles Harris, Associates.

The deceases announced during the year have been: Dr. Michael Faraday, and the Earl of Rosse, Honorary Members; Nichol Baird, John Cass Birkinshaw, William Carpmael, James Combe, Alexander Gibb, William Gilbert Ginty, James Cramond Gunn, Robert Hawthorn, Edward Humphrys, Parkin Jeffcock, Alfred King, George May, Auguste Perdonnet, and James Cobby Street, Members; John Bethell, Christopher Joseph Cato, Edward Magdalen Joseph Delaney, Frederick Samuel Homfray, Captain Mark Huish, Edward Loysel, William Jopling Nesham, Thomas Richardson, Ph. D., Lieutenant-Colonel William Drummond Alexander Robertson Short, R.E., and Henry Stone, Associates.

Biographical notices of some of those whose loss the Institution has thus to deplore will be given in an Appendix.

The following summary of the Statements of Receipts and Expenditure, as signed by the Auditors, for the years ending the 30th of November, 1866, and the 30th of November, 1867, will serve to show, briefly, the sources of income, and the way that income has been disbursed.

The Receipts have comprised—

	1866.						1867.					
	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
From subscriptions, fees, &c., exclusive of Building Fund.	4,437	14	4				4,657	10	0			
„ dividends on investments not in trust . .	506	15	4				484	5	8			
				4,944	9	8				5,141	15	8
„ Building Fund fees, on election . .	874	13	0				715	1	0			
„ dividends on investments on this account .	119	16	2				129	0	7			
				994	9	2				844	1	7
„ dividends on Trust Funds				360	5	5				371	15	5
Totals . .				£6,299	4	3				£6,357	12	8

The Expenditure during the same periods has been—

		£. s. d.	£. s. d.	£. s. d.
To disbursements, including Minutes of Proceedings (less received on that account)		4,153 2 4		4,446 4 10
„ Premiums under trusts ..		130 18 4		163 10 3
„ Investments :—				
Telford Fund (unexpended dividends)	509 6 7		185 10 7	
Miller Fund, ditto	515 11 10		230 6 2	
General account .	1,510 14 4		..	
Building Fund .	425 5 0		1,222 4 6	
		2,960 17 9		1,638 1 3
Totals . .		£7,244 18 5		£6,247 16 4

The cash balances exceed by £109. 16*s.* 4*d.* the sums in hand at the same date last year, making up the difference between the two sides of the account for 1867, as presented in the foregoing analysis.

During the past year, the balance of the Building Fund fees received last session, and all those received in the current session, with the dividends on this account, together amounting to £1,222. 4*s.* 6*d.*, as also the unexpended dividends on the Telford and the Miller Trust Funds, being £185. 10*s.* 7*d.* and £230. 6*s.* 7*d.*, respectively, have been invested in the purchase of £1,349. 14*s.* 7*d.*, £200. 11*s.* 5*d.*, and £248. 19*s.* 8*d.* Reduced Three per Cent. Annuities.

The sums of £287. 15*s.* Consols, and of £227. 8*s.* Reduced Annuities—part of the estate of our first President, Thomas Telford, whose decease occurred in September, 1834,—have been transferred into the name of the Corporation of The Institution of Civil Engineers in the Bank books. These were understood to be the final sums payable to the Institution out of this estate.

By the will of the late Mrs. Locke, the Institution was bequeathed the well-known portrait, by Sir Francis Grant (President of the Royal Academy), of our esteemed and distinguished Past-President, Mr. Joseph Locke, M.P., and a sum of Two Thousand Pounds (£2,000), free of legacy duty. The portrait has been received, and is now placed on the walls of the Meeting-room ; and the amount of the other legacy will be paid by the executors in due course. The Council tendered, in the name of the Institution, their condolence to the surviving relatives of the late Mrs. Locke, at the lamented death of the widow of their old colleague.

The nominal value of the realized property belonging to, and under the charge of, the Institution now consists of—

I. General Funds.

	Nominal Value. £. s. d.	£. s. d.
1. Stephenson Bequest, North Eastern Railway Four per Cent. Debenture Stock . .	2,000 0 0	
2. Miller Bequest, Reduced Three per Cent. Consols	2,133 6 8	
3. Errington Bequest, Great Northern Railway Four per Cent. Debenture Stock . .	1,000 0 0	
4. Institution Investments:—		
Great Eastern Railway Four per Cent. Debenture Stock . . £3,650		
Great Northern Ditto . . . 1,400		
London and North Western Ditto . 1,162		
London Brighton and South Coast Company Ditto 1,000		
North Eastern Ditto . . . 500		
	7,712 0 0	
		12,845 6 8

II. Building Fund.

1. Great Northern Railway Four per Cent. Debenture Stock	500 0 0	
2. London and North Western ditto . . .	1,338 0 0	
3. Great Eastern ditto	1,100 0 0	
4. Reduced Three per Cent. Consols . . .	913 16 2	
5. Ditto ditto Annuities . .	435 18 5	
		4,287 14 7

III. Trust Funds.

1. Telford Fund:—			
Three per Cent. Consols .	£2,551 15 10		
Ditto . .	287 15 0		
Three per Cent. Annuities .	2,342 17 1		
Ditto . .	227 8 0		
		5,409 15 11	
Ditto Unexpended Dividends, Three per Cent. Consols . . .	1,775 19 8		
Ditto, Annuities	601 10 9		
Ditto do.	200 11 5		
		2,578 1 10	
			7,987 17 9
2. Manby Premium:—			
Great Eastern Railway, Norfolk Five per Cent. Preference Stock			200 0 0
3. Miller Fund:—			
Lancashire and Yorkshire Railway Four per Cent. Debenture Stock.	£2,000 0 0		
Great Eastern, ditto . .	1,100 0 0		
		3,100 0 0	
Carried forward . .		3,100 0 0	8,187 17 9 17,133 1 3

	£.	s.	d.	£.	s.	d.	£.	s.	d.
Brought forward . .	3,100	0	0	8,187	17	9	17,133	1	3
Unexpended Dividends, Three per Cent. Consols 582 18 6									
Ditto, Annuities 248 19 8									
	831	18	2						
				3,931	18	2			
							12,119	15	11
Total Nominal Value of different Securities . .							£29,252	17	2
Cash balances:—									
On deposit at Union Bank, New Building Account				£202	1	10			
In the hands of the Treasurer, Dec. 1, 1867 . .				367	13	4			
Balance of Petty Cash in the hands of the Secretary				13	5	8			
							583	0	10
Together amounting to							£29,835	18	0

as against £26,709. 11*s.* 2*d.*, at the date of the last Report.

The several Funds above enumerated have thus been increased to the amount of £3,126. 6*s.* 10*d.*, as follows:—

I. General Funds.

Institution Investments:—									
North Eastern Railway Four per Cent. Debenture Stock				£500	0	0			
Excess of Cash balances on previous Report .				109	16	4			
							609	16	4

II. Building Fund.

Reduced Three per Cent. Consols . . .				913	16	2			
,, ,, ,, Annuities . .				435	18	5			
On Deposit at Union Bank—New Building Account				202	1	10			
							1,551	16	5

III. Trust Funds.

Telford Fund:—									
Reduced Three per Cent. Consols	287	15	0						
,, — ,, ,, Annuities	227	8	0						
				515	3	0			
Unexpended Dividends Three per Cent. Annuities				200	11	5			
							715	14	5
Miller Fund:—									
Unexpended Dividends Three per Cent. Annuities . .							248	19	8
							£3,126	6	10

The following is a Summary of the different Securities in which the above Funds are placed—

	£.	s.	d.	Nominal Value. £.	s.	d.
Government Stocks :—						
Three per Cent. Consols	£8,245	11	10			
Three per Cent. Annuities	4,057	5	4			
				12,302	17	2
Great Eastern Railway :—						
Five per Cent. Preference Stock	200	0	0			
Four per Cent. Debenture Stock	5,850	0	0			
				6,050	0	0
Great Northern Railway :—						
Four per Cent. Debenture Stock				2,900	0	0
Lancashire and Yorkshire Railway :—						
Four per Cent. Debenture Stock				2,000	0	0
London and North Western Railway :—						
Four per Cent. Debenture Stock				2,500	0	0
London, Brighton, and South Coast Railway :—						
Four per Cent. Debenture Stock				1,000	0	0
North Eastern Railway :—						
Four per Cent. Debenture Stock				2,500	0	0
Total Nominal Value				£29,252	17	2

The amount of subscriptions still remaining due, on the 30th of November last, from members of all classes (exclusive of those who are more than three years in arrear, including the current year,) is—

		£.	s.	d.	£.	s.	d.
For 1867.	From members of all classes residing abroad	133	7	6			
	Ditto, in the United Kingdom	166	19	0			
					300	6	6
For 1866.	From members of all classes residing abroad.	45	3	0			
	Ditto, in the United Kingdom	63	0	0			
					108	3	0
For 1865.	From members of all classes residing abroad	16	5	6			
	Ditto, in the United Kingdom	12	12	0			
					28	17	6
	Total				£437	7	0

The Bye-laws direct, in reference to the election of officers, that "No Member shall be elected to the office of President more than two years consecutively," and that "the senior Vice-President in duration of office is to be nominated for President." Accordingly, in the balloting-list issued to the Members and Associates, it will have been noticed that Mr. Charles Hutton Gregory is proposed for President, in succession to Mr. Fowler, whose term of office has expired. Two vacancies have occurred among the Vice-Presidents, and to fill those vacancies Mr. T. E. Harrison and Mr. Vignoles have been nominated. The names of Messrs. J. W. Bazalgette, F. J. Bramwell, J. D'A. Samuda, M.P., and Edward Woods, Mem-

bers, and of Messrs. Talbot Bury, J. H. Lloyd, F. Ransome, and Captain H. W. Tyler, Associates, have been added to the list to complete the number required by the Rules; and all these gentlemen have promised to serve if elected.

With this Report, the duties of the present Council are brought to a conclusion. In their opinion, and they trust also in that of the general body, the Institution during the past Session has fairly fulfilled its obligations—has been the means of imparting much valuable information—has tended to stimulate the growth of knowledge, and generally to advance the status of the profession.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer				294	16	10
— Subscriptions and Fees:—						
Arrears	217	3	6			
Current	3,731	10	6			
Subscriptions for 1868 (in advance)	56	14	0			
Fees	396	18	0			
Life Compositions	111	0	6			
				4,513	6	6
— Building Fund				715	1	0
— Publication Fund				81	18	0
— Council Fund				50	0	0
— Publications :—Sale of Transactions				404	3	10
— Telford Fund :—						
Dividends—1 Year, on £2,551. 15*s.* 10*d.*, Three per Cent. Reduced Consols	75	5	0			
Ditto, 1 Year, on £2,342. 17*s.* 1*d.*, Three per Cent. Reduced Annuities	69	2	4			
Ditto, 1 Year, on £1,775. 19*s.* 8*d.*, Three per Cent. Reduced Annuities	52	7	6			
Ditto, 1 Year, on £601. 10*s.* 9*d.*, Three per Cent. Reduced Consols	17	17	6			
Ditto, ½ Year, on £227. 8*s.*, Three per Cent. Reduced Annuities	3	7	1			
				217	19	5
— Manby Premium :—						
In Advance by the Donor, in consequence of the Suspension of Payment of 1½ Year Dividends				14	15	0
— Stephenson Bequest :—						
Dividends, 1 Year, on £2,000, North Eastern Railway Company, Four per Cent. Debenture Stock				78	13	4
— Miller Fund :—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Company, Four per Cent. Debenture Stock	78	13	4			
Ditto, 1 Year, on £1,100, Great Eastern Railway Company, Four per Cent. Debenture Stock	43	5	4			
Ditto, 1 Year, on £582. 18*s.* 6*d.*, Three per Cent. Reduced Consols	17	2	4			
				139	1	0
— Miller Bequest :—						
Dividends, 1 Year, on £2,133. 6*s.* 8*d.*, Three per Cent. Reduced Annuities				62	18	8
— Errington Bequest :—						
Dividends, 1 Year, on £1,000, Great Northern Railway Company, Four per Cent. Debenture Stock				39	6	8
— Institution Investments :—						
Dividends, 1 Year, on £3,650, Great Eastern Railway Company, Four per Cent. Debenture Stock	143	11	4			
Ditto, 1 Year, on £1,400, Great Northern Railway Company, Four per Cent. Debenture Stock	55	1	4			
Ditto, 1 Year, on £1,162, London and North Western Railway Company, Four per Cent. Debenture Stock	45	14	4			
Carried forward	244	7	0	6,612	0	3

from the 1ST DEC., 1866, *to the* 30TH NOV., 1867.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By Balance of Petty Cash due to the Secretary				23	14	2
— House, Great George Street, for Rent, &c.:—						
Alterations	17	10	6			
Furniture	38	4	4			
Rent	368	15	0			
Rates and Taxes	35	18	2			
Insurance	15	6	9			
				475	14	9
— Salaries				750	0	0
— Clerks, Messengers, and Housekeeper				322	2	0
— Postage and Parcels:—						
Postage	39	12	6			
Parcels	2	14	10			
				42	7	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				164	16	7
— Coals, Candles, Oil, and Gas:—						
Coals	20	0	0			
Candles	0	3	3			
Oil	3	17	3			
Gas	41	0	5			
				65	0	11
— Tea and Coffee				37	1	8½
— Library:—						
Catalogue	8	2	6			
New Books	43	5	2			
Periodicals	18	15	8			
Binding Books	55	12	1			
Evening Attendance	66	5	0			
New Book Cases	20	17	0			
				212	17	5
— Publication, Minutes of Proceedings				2,243	7	11
— Telford Premiums				158	7	6
— Manby Premium				5	2	9
— Diplomas				38	8	11
— Manuscripts, Original Papers, and Drawings				0	3	0
— Annual Dinner				86	10	10
— Winding and Repairing Clocks				2	8	6
— Incidental Expenses:—						
Christmas Gifts	1	19	0			
Assistance at Meetings	9	7	0			
Beating Carpets and Sweeping Chimneys	3	2	6			
Household Utensils, Repairs, and Expenses	40	0	1			
				54	8	7
— Legal Expenses, Tooke and Co. Disbursements out of Pocket from 1862–66				31	19	4
— Jones Memorial				41	19	10
Carried forward				4,756	12	0½

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
Brought forward	244	7	0	6,612	0	3
To Institution Investments:—						
Dividends, 1 Year, on £1,000, London, Brighton, and South Coast Railway Company, Four per Cent. Debenture Stock	39	6	8			
Ditto, 1 Year, on £500, North Eastern Railway Company, Four per Cent. Debenture Stock	19	13	4			
				303	7	0
— Building Fund Investments:—						
Dividends, 1 Year, on £500, Great Northern Railway, Four per Cent. Debenture Stock	19	13	4			
Ditto, 1 Year, on £1,338, London and North Western Railway Company, Four per Cent. Debenture Stock	52	12	4			
Ditto, 1 Year, on £1,100, Great Eastern Railway Company, Four per Cent. Debenture Stock	43	5	4			
Ditto, ½ Year, on £227. 8s., Three per Cent. Reduced Consols	13	9	7			
				129	0	7
— Donations to Library				8	3	0
— Her Majesty's Commissioners for the Paris Exhibition. Repayment of Monies disbursed by the Institution				3	19	11
— Library				0	2	7
				£7,056	13	4

from the 1ST DEC., 1866, *to the* 30TH NOV., 1867.

PAYMENTS.

Cr.	£.	s.	d.	£	s.	d.
Brought forward . . .				4,756	12	0½
By Subscription Paid in Error				3	3	0
— Benevolent Fund				39	1	3
— Armstrong—Russell Inquiry				238	16	9½
				5,037	13	1
— Telford Fund.—Balance of Dividends not yet Expended in Annual Premiums. Invested in £200. 11*s.* 5*d.* Three per Cent. Reduced Annuities	185	10	7			
— Miller Fund, ditto ditto. Invested in £248. 19*s.* 8*d.*, Three per Cent. Reduced Annuities . . .	230	6	2			
— Building Fund.—Repayment of Amount received to October 10, 1867. Invested in £1,349. 14*s.* 7*d.*, Three per Cent. Reduced Annuities	1,222	4	6			
				1,638	1	3
— Balance of Petty Cash, Dec. 1, 1867, in the hands of the Secretary				13	5	8
— Balance in the hands of the Treasurer				367	13	4
				£7,056	13	4

Examined and compared the above Account with the Vouchers and the Cash Book, and find this account to be correct, leaving a Balance in the hands of the Treasurer of Three Hundred and Sixty-seven Pounds, Thirteen Shillings, and Fourpence.—Nov. 30th, 1867.

(Signed) GEORGE P. BIDDER, JUN., JAMES D. BALDRY, } *Auditors.*
JAMES FORREST . . . *Secretary.*

December 13th, 1867.

PREMIUMS AWARDED.

Session, 1866-67.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, in Books, to James T. Chance, M.A., Assoc. Inst. C.E., for his Paper "On Optical Apparatus used in Lighthouses."
2. A Telford Medal, and a Telford Premium, in Books, to Edward Byrne, M. Inst. C.E., for his Paper "Experiments on the Removal of Organic and Inorganic Substances in Water."
3. A Telford Medal, to George Biddell Airy, Astronomer Royal, Hon. M. Inst. C.E., for his Paper "On the Use of the Suspension Bridge with Stiffened Roadway for Railway and other Bridges of Great Span."

*4. A Watt Medal to Colonel Sir William Thomas Denison, K.C.B., R.E., Assoc. Inst. C.E., for his Paper on "The Suez Canal."

5. A Watt Medal, and a Telford Premium, in Books, to John Bourne, for his Paper on "Ships of War."

*6. A Telford Premium, in Books, to Captain Henry Whatley Tyler, Assoc. Inst. C.E., for his Paper "On the Working of Steep Gradients and Sharp Curves on Railways."

*7. A Telford Premium, in Books, to William Henry Preece, Assoc. Inst. C.E., for his Paper, "On the Best Means of Communication between the Passengers, Guards, and Drivers of Trains in Motion."

*8. A Telford Premium, in Books, to William Alexander Brooks, M. Inst. C.E., for his Paper on "The River Tyne."

9. The Manby Premium, in Books, to Charles Douglas Fox, M. Inst. C.E., for his Paper "On Light Railways in Norway, India, and Queensland."

* Have previously received Telford Medals.

SUBJECTS FOR PREMIUMS.

Session, 1867-68.

The Council of the Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as—1. Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2. Descriptions of Engines and Machines of various kinds; or, 3. Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications, the Council will be prepared to award the Premiums arising out of special Funds devoted for the purpose.

The Council will be glad to receive, for the purpose of forming an "Appendix" to the Minutes of Proceedings, the details and results of any Experiments, or Observations, on Subjects connected with Engineering Science, or Practice.

1. On the Theory and Details of Construction of Metal and Timber Arches.
2. On Land-slips, with the best means of preventing, or arresting them, with examples.
3. On the Principles to be observed in Laying-out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghâts, the Rocky Mountains of America, and similar cases.
4. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
5. On the Pneumatic System for the conveyance of Passengers and Goods.
6. On the Systems of Fixed Signals at present in use on Railways.
7. On the most suitable Materials for, and the best mode of formation of, the Surfaces of the Streets of large Towns.
8. On the Construction of Catch-water Reservoirs in Mountain Districts, for the Supply of Towns, or for Irrigation, or Manufacturing Purposes.

9. Accounts of existing Waterworks; including the source of supply, a description of the different modes of collecting and filtering, the distribution throughout the streets of Towns, and the general practical results.
10. On the Benefits and Expedients of Irrigation in India and in other warm climates; and on the proper Construction of Irrigating Canals, so as to avoid erosion or silting, and to prevent the growth of weeds.
11. On the best mode of Deodorising and Filtering, or otherwise of precipitating Sewage, and of applying it to the land.
12. On the Ventilation of Sewers.
13. On the Ventilation and Warming of Public Buildings.
14. On the best means of Manufacturing Gas of high Illuminating Power; and on the Construction of Gasworks, the most economical system of distribution of Gas, and the best modes of Illumination in Streets and Buildings.
15. A History of any Fresh Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works which may have been executed upon it, and of the effects of the works; particularly of the relative value of Tidal and Fresh Water, of the effect of Enclosures from the Tidal Area upon the general régime, of Sluicing where applied to the improvement of the entrance or the removal of a Bar, and of Groynes, or Parallel Training Walls. Also, of Dredging, with a description of the Machinery employed, and the cost of raising and depositing the material.
16. On the Construction of Tidal, or other Dams, in a constant, or variable depth of water; and on the use of Wrought Iron in their construction.
17. On the Arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
18. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
19. On the Construction of Lighthouses, their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
20. On the Measure of Resistance to Bodies passing through Water at high Velocities.
21. On Ships of War, with regard to their Armour, Ordnance, mode of Propulsion, and Machinery.
22. On the measures to be adopted for protecting Iron Ships from Corrosion.

23. On the Construction and Performance of Turbines of all classes.
24. On the comparative cost of Conveying Coals by Railways and by Screw Colliers.
25. On the present systems of Smelting Iron Ores; of the conversion of Cast Iron into the malleable state, and of the manufacture of iron generally, comprising the distribution and management of Ironworks.
26. On the Manufacture of Iron for Rails and Wheel Tires, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and bars of Iron of large sectional area.
27. On the Bessemer and other processes of Steel-making; on the present state of the Steel Manufacture on the Continent of Europe; and on the employment of castings in Steel for Railway Wheels and other objects.
28. On the Use of Steel for the Tires and Cranked Axles of Locomotive Engines, especially with reference to its durability and the cost of repairs, as compared with Iron of acknowledged good quality; and on the use of Steel Bars and Plates generally in Engine-work and Machinery, for Boilers and for Shipbuilding, as well as for Bridges.
29. On the safe working strength of Iron and Steel, including the results of experiments on the Elastic Limit of long bars of Iron, and on the rate of decay by rusting, &c., and under prolonged strains.
30. On the present state of Submarine Telegraphy, and on the Transmission of Electrical Signals through Submarine Cables.
31. On the present relative position of English and Continental Engineering Manufactories, especially with reference to their comparative positions in respect of the cost, and the character of the work produced.

The Council will not consider themselves bound to award any Premium, should the Communication not be of adequate merit, but they will award more than one Premium, should there be several communications on the same subject deserving this mark of distinction. It is to be understood that, in awarding the Premiums, no distinction is made, whether the Communication has been received from a Member, or an Associate of the Institution, or from any other person, whether a Native, or a Foreigner.

The Communications must be forwarded, on or before the 1st of February, 1868, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information, may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, *Great George Street, Westminster, S.W.,*
October, 1867.

NOTICE.

It has frequently occurred that, in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal Subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering or Surveying."

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper; but should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.

RECEIVED BETWEEN JUNE 30th, 1866, AND NOVEMBER 30th, 1867.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Airy, G. B. No. 1176.—On the use of the Suspension Bridge with Stiffened Roadway for Railway and other Bridges of Great Span.

Airy, W. No. 1184.—On the Experimental Determination of the Strains on the Suspension Ties of a Bowstring Girder.

Allen, E. E. No. 1171.—On the Propelling Power of Iron-plated Ships of War.

Bourne, J. F. No. 1185.—Roman Rock Lighthouse, Simon's Bay, Cape of Good Hope.

Byrne, E. No. 1183.—Experiments on the Removal of Organic and Inorganic Substances in Water.

Chance, J. T. No. 1180.—On Optical Apparatus used in Lighthouses.

Clark, E. No. 1179.—On Engineering Philosophy: the Durability of Materials.

Denison, Col. Sir W. T., K.C.B., R.E. No. 1172.—The Suez Canal.

Fox, C. D. No. 1177.—On the Widening of the Victoria Bridge and the Approaches to the Victoria Station; and on New Railways at Battersea

Gainsford, T. R. No. 1174.—An Account of the Construction of a Railway Tunnel, or Covered way, at Bradford (Yorkshire); particularly regarding its Foundations among abandoned Coal and Ironstone Workings.

Haslett, C. No. 1169.—On the Measurement of Earthwork for Embankments and Cuttings.

Hooper, H. No. 1181.—On New Ferry and New Brighton Piers.

Howden, A. C. No. 1186.—Floods in the Nerbudda Valley; with Remarks on Monsoon Floods in India generally.

Latham, G. No. 1189.—Proposed Overland Route, *viâ* Turkish Arabia and the Persian Gulf.

Longridge, J. A. No. 1175.—On the Construction of Artillery.
McAlpine, W. J. No. 1187.—On the Supporting Power of Piles.
——— No. 1188.—On the Pneumatic Process for Sinking Iron Columns, as practised in America.
Rigg, A., jun. No. 1170.—Steam Boiler Explosions.
Shand, J. No. 1182.—On Additional Water Supply, and Improved Fire Extinguishing arrangements for the Metropolis.
Valentine, A. No. 1173.—Description of a Stop Sluice in Marshland.
Wilson, W. No. 1178.—Description of the Victoria Bridge, on the line of the Victoria Station and Pimlico Railway.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Admiralty, through G. B. Airy, Astronomer Royal. Astronomical and Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich, in the years 1864 and 1865, under the Direction of George Biddell Airy, Astronomer Royal. 2 vols. 4to. London, 1866-67.

——— Ditto. Appendix I. On the Value of the Moon's Semidiameter, as obtained by the investigations of Hugh Breen, from Occultations observed at Cambridge and Greenwich. 4to. London, 1866.

——— Ditto. Appendix II. Reduction of the Greenwich Planetary Observations, 1831 to 1835. 4to. London, 1836.

——— Rates of Chronometers on trial for purchase by the Board of Admiralty at the Royal Observatory, Greenwich, 1867. 4to. No place or date.

——— Verification and Extension of La Caille's Arc of Meridian in the Cape of Good Hope. By Sir Thomas Maclear. 2 vols. 4to. Plates. London, 1866.

Académie Royale de Belgique. Annuaires 1866, 1867. 2 vols. 12mo. Portraits. Bruxelles, 1866-67.

——— Bulletins. 2^{me} Série. Tomes XX.—XXIII. 4 vols. 8vo. Plates. Bruxelles, 1865-66-67.

——— Mémoires Couronnés et Autres Mémoires. Tome XVIII. 8vo. Plates. Bruxelles, 1866.

——— Mémoires de l'Académie. Tome XXXV., XXXVI. 2 vols. 4to. Plates and cuts. Bruxelles, 1865.

——— Tables Générales et Analytiques du Recueil des Bulletins. 8vo. Bruxelles, 1867.

Aitken, R. Main Drainage of Bombay. Preliminary Report of the Executive Engineer to the Municipality of Bombay. With Appendix, being Observations of the Tidal Currents round the Island of Bombay. Tract. 8vo. Map. Bombay, 1866.

Akademie der Wissenschaften zu München. Sitzungsberichte 1866 I. Heft. III.—1867 II. Heft. I. 8vo. München, 1866-67.

DONORS. TITLE OF WORK.

Albano, B. Une Visite au Chateau Caradoc. [Extrait du Journal le Courrier de Bayonne, 3 et 10 Septembre, 1865.] Lettres d'un Touriste. [Extraites du Journal l'Indicateur de Biarritz, 1 et 8 Octobre, 1865.] Tract. 8vo. Photograph. Bayonne, 1861.

[Bound together.]

Anderson, W. On Railway Bridges of Small Span, and Cross Beams of Railway Bridges. By W. Anderson. Tract. 8vo. No place or date.

[From the "Trans. Inst. C.E.I.," 1866.]

Andrews, A. T. Cape of Good Hope. Report of the Chief Inspector of Public Works for the Year 1866. Folio. Cut. Cape Town, 1867.

Anonymous. Reply of the President and Directors of the Southampton Chamber of Commerce to the Pretensions of Plymouth and Falmouth as a West India Mail Packet Station. Second edition. 8vo. London, 1867.

———— The Viceroy of India and Sir Bartle Frere on the Indus Railway. By a Scindhee. Tract. 8vo. London, 1867.

———— Universal Suffrage and Vote by Ballot in Australia. An Inquiry addressed to the Right Hon. the Earl of Derby. By an Old Colonist. Tract. 8vo. London, 1867.

Architecten und Ingenieur Vereins zu Hannover. Zeitschrift. Band XIII. Jahrgang, 1867. 4to. Plates and cuts. Hannover, 1867.

Architectural Publication Society. The Dictionary of Architecture. Text. Parts XVI. and XVII. Iron-Keyser. Plates J—T. Folio. London, 1867.

Arntz, R. R. The Board of Works for the Westminster District. Report of Mr. R. R. Arntz, Surveyor to the Board, with reference to the working of Steam Rollers on Macadamized Roads, and as to other matters connected with the Management of the City of Paris. Tract. 8vo. No place, 1866.

Association for the Prevention of Steam Boiler Explosions, Manchester. Chief Engineer's Monthly Reports to Executive Committee. Brief Abstract only. Nos. XXXVII.—LXX. March, 1865—October, 1867. 8vo. Cuts. Manchester, 1865-67.

Austin, C. E. On the Utilization of Sewage by Filtration and Irrigation. By C. E. Austin. 8vo. Plates. No place or date.

Balfour, Major-General. On the Budgets and Accounts of England

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and France. By Major-General Balfour, C.B. 8vo. London, 1866.

[Excerpt "Journal of the Statistical Society," 1866.]

Bassett, A. On Patent Fuel; or the Utilization of Small Coal. By Alexander Bassett. Tract. 8vo. Newport, 1867.

[From the "Proc. South Wales Inst. Eng.," 1867.]

Bateman, J. F. On a Constant Supply of Water for London. By J. F. Bateman. 8vo. London, 1867.

[Excerpt "Social Science Journal," vol. i., No. 7.]

Bayly, W. C. House of Representatives. Letter of the Secretary of State, transmitting a Report of the Commercial Relations of the United States with Foreign Nations, for the year ending September 30, 1861. 4to. Washington, 1862.

Beardmore, N. Report on the Improvement of the River Lee Navigation. By N. Beardmore. 8vo. Plates. Hertford, 1859.

Bell, R. B. On Patent Slip Docks. By R. Bruce Bell. Tract. 8vo. Plates. Glasgow, 1859.

[Excerpt "Trans. Inst. Eng. Scot.," 1858.]

Bodde, D. An Essay, to show that Petroleum may be used with advantage in manufacturing operations for the purpose of Heating Steam Boilers and Generating Steam. By D. Bodde. Tract. 8vo. The Hague, 1866.

Bodmer, R. Specifications of the Patented Inventions of John George Bodmer. 8vo. 2 vols. Plates. London. Various dates.

Boult, J. Further Observations on the Alleged Submarine Forests on the Shores of Liverpool Bay and the River Mersey, in reply to Dr. Hume's communication of July 10, 1865. By Joseph Boult. Tract. 8vo. Liverpool, 1867.

[From the "Transactions of the Historic Society of Lancashire and Cheshire," 1865.]

Bouniceau, M. Ponts et Chaussées. Departement de la Seine Inférieure. Port du Hâvre. 2e Arrondissement. Construction d'une Forme Sèche. Devis et Cahier des Charges. MM. Bouniceau et Bellot, Ingénieurs. Folio. Plan. Le Hâvre, 1867.

[Lithographed.]

Bourne, J. On the Proper Form of Ships. By John Bourne. Tract. 4to. Cuts. London, 1867.

[Excerpt "Trans. Inst. N. A.," vol. 8.]

Braidwood, Mrs. Fire Prevention and Fire Extinction. Including Fire-proof Structures, Fire-proof Safes, Public Fire Brigades, Private Means for Suppressing Fires, Fire Engines,

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Fire Annihilators, Portable Fire-escapes, Water-supply. By James Braidwood. With Memoir, Portrait, and cuts. 8vo. London, 1866.

Bramwell, F. J. Specifications of Sarah Guppy and Samuel Guppy. Bridges and Railroads. 8vo. London, 1856.

Brewster, Sir D. The History of the Invention of the Dioptric Lights, and their introduction into Great Britain. By Sir David Brewster. Tract. 8vo. London, 1867.

Bristow, H. W. On the Lower Lias or Conglomerate of a part of Glamorganshire. By H. W. Bristow. Tract. 8vo. Cut. London, 1867.

[Excerpt "Quarterly Journal of the Geological Society," 1867.]

British Association for the Advancement of Science. Report of the Thirty-fifth Meeting of the British Association for the Advancement of Science, held at Birmingham, in September, 1865. 8vo. Plates, diagrams and cuts. London, 1866.

———— Ditto, Thirty-sixth Meeting, held at Nottingham, in August, 1866. 8vo. Plates and cuts. London, 1867.

British Association of Gas Managers. Report of Proceedings of the First, Second, Third, and Fourth Annual Meetings. Tracts. 8vo. Plates and cuts. Manchester, 1864-67.

———— Rules and Regulations, and List of Members. Tract. 8vo. Manchester, 1867.

Browne, J. N. Prospectus of "The British Patent Wood Preserving Company." Tract. 8vo. Plate. London, 1866.

Canadian Institute. Canadian Journal. Nos. LXIII.—LXV. 8vo. Plates and cuts. Toronto, 1866-67.

Carr, T. Carr's Patent Disintegrator. Tract. 8vo. No place or date.

———— New Treatise on Carr's Patent Disintegrator, treated in a popular and familiar manner, apart from technicalities and detail. Tract. 8vo. Cuts. No place, 1866.

Cayley, Prof. A. A Series of Published Memoirs on Mathematical Subjects, chiefly extracted from the "Philosophical Transactions" and the "Transactions of the Cambridge Philosophical," and the "Royal Astronomical" Societies. With a "List of Mathematical Works, 1841-62;" in all, 34 Pamphlets. 8vo. and 4to. Various places and dates.

Cerero, Capt. R. Estudios sobre las Maquinas empleadas en las Construcciones y Aplicacion de la Fuerza Motora del Vapor en los Trabajos Publicos. Tract. 8vo. Plates. Madrid, 1865.

Chalmers, J. The Channel Railway connecting England and

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France. By James Chalmers. Second Edition. 8vo. Plates. London, 1867.

Chemical Society. Journal. Series 2, Vol. IV. July, 1866. Series 2, Vol. V. November, 1867. 8vo. Cuts. London, 1866-67.

Cialdi, Comm. A. Les Ports-Canaux. Article extrait de l'ouvrage sur les Mouvement des Ondes sur les Courants de la Mer, et spécialement sur les Courants Littoraux. Par le Commandeur Alexandre Cialdi. 8vo. Plates. Rome, 1866.

———— Sul Moto Ondoso del Mare; e su le Correnti di Esso, specialmente su quelle Littorali. Pel Comm. Alessandro Cialdi. 8vo. Plate. Roma, 1866.

Collins, W. W. Le Diverse et Artificiose Machine del Capitano Agostino Ramelli dal Ponte della Tresia Ingegnero del Christianissimo Re di Francia et di Pollonia. Nelle quali si Contengono varii industriosi Monumenti, degni di grandissima Speculatione per Cavarne beneficio infinito in ogne forte d'operatione. Composte in lingua Italiane et Francese. Folio. Plates. Parigi, 1588.

———— Teatro de los Instrumentos y Figuras Matematicas y Mecanicas. Libro muy util y necessario para todos estados de personas. Compuesto por Diego Besson, dotor matematico Frances. Con las interpretaciones de cada figura echas por Francesco Beroaldo. Nuevamente impresso. Folio. Plates. Leon de Francia, 1602.

Committee of Council on Education. The Chemical Laboratories in course of erection in the Universities of Bonn and Berlin. Report addressed to the Right Honourable the Lords of the Committee of Council on Education. By A. W. Hofmann, LL.D. Folio. Cuts. London, 1866.

Commissioners for the Exhibition of 1851. Fifth Report of the Commissioners, to the Right Hon. Gathorne Hardy, one of her Majesty's Principal Secretaries of State. 8vo. Plate and map. London, 1867.

Condy, H. B. On the Purification of Water and Air, and the Use of the Alkaline Permanganates as Purifying Agents. By Henry Bollmann Condy. Tract. 8vo. London, 1862.

Cooke, W. F. The Electric Telegraph. Was it invented by Professor Wheatstone? By W. F. Cooke. 2 vols. 8vo. Plates. London, 1856-1857.

Corporation of London. Catalogue of Sculpture, Paintings, Engravings, and other Works of Art belonging to the Corporation, together with Books not included in the Catalogue of the Guildhall Library. 8vo. London, 1867.

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Corporation of London. Catalogue of the Library of the Corporation of London, Seventh Supplement. 8vo. London, 1867.

Corps of Royal Engineers. A Catalogue of the Dublin Branch of the Royal Engineers Corps' Professional Library. Completed to 19th December, 1866. 8vo. Dublin, 1866.

[Additions in MS.]

———— Catalogue of Books, Maps, and Plans in the General Corps' Libraries of the Royal Engineers. 4to. London, 1866.

———— Catalogue of the Royal Engineer Establishment Professional Library at Chatham. 8vo. London, 1859.

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January 14, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—DAVID PHILLIPS, as a Member; THOMAS PHILIP SHERARD CROSTHWAIT, WILLIAM COOKE FABER, GEORGE FARREN, Major JAMES GEORGE ROCHE FORLONG, THOMAS ELLIS OWEN, MIDDLETON RAYNE, HENRY YARKER RICHARDSON, JAGANNATH SADASEWJEE, JAMES STEWART, Captain HECTOR TULLOCH, R.E., and CHARLES WAWN, as Associates.

It was announced that the following Candidates having been duly recommended, had been admitted by the Council, under the provisions of Section IV. of the Bye-Laws, as Students of the Institution:—HENRY ADAMS, CHARLES AUGUSTUS ALBERGA, ROBERT WILLIAM PEREGRINE BIRCH, JOHN MONTRIOU CAMPION, LINDSAY HEATH, ARTHUR WILLOUGHBY HEMANS, OSBERT HENRY HOWARTH, WILLIAM HENRY KING, FRANK HOWARD LANDON, ARTHUR HEMERY LE BRETON, FREDERICK HERBERT MOLLETT, GEORGE PULLIN POCOCK, GEORGE HENRY ROBERTS, EDWARD LEE ROBERTSON, DAMPIER SEABROOK SHAW, JAMES HENRY WALLER, and FRANCIS WILTON.

Mr. CHARLES HUTTON GREGORY addressed the Meeting in the following terms, on taking the Chair, for the first time, after his election as President:—

In addressing you, Gentlemen, as I now do for the first time as President of the Institution of Civil Engineers, I feel deeply the honour you have conferred upon me by electing me to be the successor of the many distinguished men who have hitherto occupied this chair. If I can never hope to leave behind me such a reputation as they have achieved by high attainments and great works, my heartiest efforts will be devoted to emulating their example, by presiding with courtesy and fairness over your deliberations, and by promoting, by every means in my power, the interests and progress of the profession, in the earnest hope that, by your kind support, and the cordial co-operation of my colleagues in the Council, this Institution may be maintained, during my tenure of office, in undiminished usefulness and honour.

Fifty years ago, on the 2nd of January, 1818, this Institution was founded, its members then being only six in number. On the 21st of March, 1820, Thomas Telford, our first President, in his inaugural address, referred to the nature of the Institution and its probable future usefulness, and pointed out the significant fact, that while, in foreign countries, such Institutions depended on Governments for their support, in this country their existence and their prosperity were dependent on the united action of the individual members. In this, our jubilee year, we may, with pardonable pride, congratulate ourselves that Telford's views have been justified, and even surpassed, in succeeding years of increasing prosperity, in our satisfactory financial condition, in our numbers, now comprising 1,472 members of all classes, in the formation of our Student Class, and our Benevolent Fund, and in the firm establishment of the Institution of Civil Engineers as the recognized representative body of the profession, comprising within its ranks, past and present, the names of so many, illustrious in abstract or practical science, whose labours have enlarged the resources of our country, and materially promoted the civilization of the world.

To trace out the progress of the Institution, and to refer to the greatest works of its members, is not my present object; indeed previous Presidents have treated these subjects so exhaustively, that such a history would be little else than a recapitulation of their addresses. But a reference to our past records has brought to light one document which I venture now to lay before you, believing that it must be interesting to every Engineer, from its authorship, and from its bearing on the history of the Institution.

At a meeting of the Council, held on December 29th, 1827, it was

"Resolved—That Mr. Tredgold be written to, requesting him to define the objects of the Institution of Civil Engineers, and to give a description of what a Civil Engineer is, in order that this description and these objects may be embodied in a Petition to the Attorney-General, in application for a Charter."

At the following meeting of Council on January 4th, 1828, the Secretary read the communication received from Mr. Tredgold, which is thus entered in the Minutes:—

"Description of a Civil Engineer,

"By Thomas Tredgold, Hon. M. Inst. C.E.

"Civil Engineering is the art of directing the great sources of power in Nature for the use and convenience of man; being that practical application of the most important principles of natural philosophy which has, in a considerable degree, realized the antici-

pations of Bacon, and changed the aspect and state of affairs in the whole world. The most important object of Civil Engineering is to improve the means of production and of traffic in states, both for external and internal trade. It is applied in the construction and management of roads, bridges, railroads, aqueducts, canals, river navigation, docks, and storehouses, for the convenience of internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the navigation by artificial power for the purposes of commerce.

"Besides these great objects of individual and national interest, it is applied to the protection of property where natural powers are the sources of injury, as by embankments for the defence of tracts of country from the encroachments of the sea, or the overflowing of rivers; it also directs the means of applying streams and rivers to use, either as powers to work machines, or as supplies for the use of cities and towns, or for irrigation; as well as the means of removing noxious accumulations, as by the drainage of towns and districts to prevent the formation of malaria, and secure the public health. This is, however, only a brief sketch of the objects of Civil Engineering, the real extent to which it may be applied is limited only by the progress of science; its scope and utility will be increased with every discovery in philosophy, and its resources with every invention in mechanical or chemical art, since its bounds are unlimited, and equally so must be the researches of its professors.

"The enterprizing Hollanders towards the close of the sixteenth century first separated Civil Engineering from architecture, under the title of hydraulic architecture; their example was followed in France towards the end of the seventeenth century, and soon afterwards was systematized in the great work of Belidor on Hydraulic Architecture.

"One of the great bases on which the practice of Civil Engineering is founded is the science of hydraulics; every kingdom, every province, every town has its wants, which call for more or less acquaintance with this science. Water, which is at once the most useful of the necessaries of life, and the most dangerous element in excess, when limited by the laws of this science is rendered the best of servants; the rolling cataract which spends its powers in idleness may be directed to drain the mine, to break the ore, or be employed in other works of labour for the use of man; the streams are collected and confined in canals for inland traffic; harbours are formed to still the raging of the waves of the ocean, and offer a safe retreat to the storm-driven mariner; and ports are provided with docks, to receive the riches of the world in security: hence arose the term hydraulic architecture; but it was too limited; the various applications of water had rendered the natural supplies in-

adequate to the wants of man, till he discovered that, combined with heat it formed a gaseous element endued with energies not less powerful than the falling cataract; its steam, confined and directed by science, became a new source of power, which in a few years altered and improved the condition of Britain, and we are every day witnessing new applications, as well as the extension of the older ones to every part of the globe."

Many of you will recognize some of the expressions of this description, which has, in fact, been abridged in our Charter; but I make no apology for giving it you entire, believing that you will appreciate its comprehensiveness, and its beauty.

Eloquent and comprehensive as the words of Tredgold were, even his almost prophetic vision forty years ago did not take in the whole of that field of usefulness now open to us, and which ever grows wider by cultivation. The contributions of science have kept pace with the growing wants of the age. Metallurgy has worked out a revolution in the treatment and application of metals; chemistry has pointed to the purification and utilization of the sewage of towns, and the relieving rivers of pollution; hydraulics have led to projects for supplying cities with water from remote mountains; electricity speeds the "winged word" in "a girdle round about the earth" more quickly than fairy magic in the dreams of poets.

If exact science has led the way, the members of this Institution have not been slow to follow with constructive science; our Proceedings are rich with the records of works great in extent or interest, but some remain to be described. The Thames Embankment, the completion of the great Sewage Works and Outfalls, the Millwall Docks, various new or modified forms of Floating Docks, the Mont Cenis Railway, the successful submerging of the Atlantic Telegraph, the latest Iron Ships, the important works of the various Metropolitan Railways, and the Public Works which have been carried out in our Colonies;—these and other undertakings recently completed, or in course of construction, will, it is to be hoped, become soon the subject of Papers and discussions.

In illustration of what has been recently done in our Colonies, I may mention that Victoria, with an annual revenue of about £3,000,000, spends about £300,000 in Roads, Bridges, and other public works; Ceylon, with a revenue of about £1,000,000, spends about £230,000; Mauritius, with a revenue of about £650,000, spends about £70,000; and the Cape, with a revenue of about £860,000, spends about £50,000. In addition to these sums, and irrespective of the Cape Railway, executed by a Company with a Colonial Guarantee on a fixed capital, the following sums have

been raised and laid out within the last few years for the construction of Railways: by Victoria £10,000,000, by Ceylon £1,750,000, and by Mauritius £1,430,000. These railways have been executed by the respective governments, without the intervention of companies; they have not been opened long enough to develop their traffic, but there is reason to believe that they will pay more than the interest on the money borrowed. It should be stated that of the sum set down as spent upon railways in Ceylon, only £800,000 was borrowed, the remainder being produced by a tax on coffee and by ordinary revenue.

At a time when so much criticism is directed to the management and effects of Railway Enterprise, it should not be forgotten how much of the present evil has arisen from unprofitable works forced on Companies by public opinion, and from the freedom with which Parliament has sanctioned competing lines. While we may deplore the individual losses which have arisen from these causes, and from over-speculation, we may recall, on the other hand, the great social and material benefits which railways have conferred on the country. Wisely or unwisely, upwards of four hundred millions have been expended upon our railways in about forty years. Irrespective of the saving of time, and the vast increase of profitable commerce to which they have given rise, it has been estimated that the saving to the public in the cost of transport alone, by the use of Railways, as compared with that by other means of conveyance, if they had been equal to such an amount of traffic, would be measured by an interest of no less than 15 per cent. on this great outlay.

The present depression of commercial enterprise may for a time check the progress of great Engineering operations, but perhaps it may give to corporate bodies a good opportunity for engaging the services of engineers in designing and carrying out many important sanitary works; and lead to the study of the numerous localities where low lands are now inadequately drained, and where the enlarged powers of the Land Drainage Act of 1861 may be successfully applied, or where superfluous supplies of water may be husbanded for irrigation and other purposes.

While many Railway Companies are suffering from the effects of the unproductive outlay of capital on branch lines, it may be well to remember the special benefits which that outlay has conferred on the landowners and inhabitants of the country traversed, benefits which the people of many districts at present unserved by railways must be anxious to possess, but for which it is clear that the necessary capital cannot now be furnished by private enterprise. It would appear, then, to be a favourable time for reconsidering the principle of constructing local lines by means of rates to be levied on the districts which would be more directly benefited by their construction.

The Government of India have availed themselves of the present opportunity to select a certain number of Engineers in this country for the prosecution of irrigation and other public works, a field in which it is believed that many more Engineers may be employed with great advantage to our possessions in the East.

When Tredgold pointed out the application of Engineering "to the protection of property where natural powers are the sources of injury," he could hardly have foreseen that in these days the attention of the Civil Engineer would have been directed to aid in constructions for defence from hostile attack, and even to the improvement of weapons of war. More than two thousand years ago, Archimedes, distinguished first in mathematical science, after carrying out the great work of the embankment of the Nile, devoted the last efforts of his genius to engineering appliances for the defence of Syracuse against Marcellus, and protracted the fall of his native city for three years. In our time, less directly and less prominently, but with marked success, the combined labours of Engineers have been applied to national defence, by the invention of improved systems of copying machinery for the perfect manufacture of small arms, by giving to machine-tools the most minute accuracy, by the application of new and more powerful machinery to the production of fresh combinations and greater masses of metal, and their reproduction as iron armour plates for land or sea defence, and still further by the designing of great guns, and of new structures for ships of war.

I need hardly refer you to the inaugural addresses of our Past-Presidents, Mr. Bidder and Mr. Hawkshaw—to the Papers contributed to this Institution, on Artillery, by Mr. Longridge, on National Defences, by Mr. G. Bidder, jun., on Iron-plated Ships, by Mr. Samuda, and on Ships of War, by Mr. Bourne, and to the valuable discussions on these Papers, in which so many distinguished Officers, and so many able Engineers have taken part within these walls, as showing that these subjects are not foreign to our profession, and that the Institution and its members have contributed, in no small degree, to their investigation. If on such an occasion as the present I may have your indulgence for alluding to a purely personal subject, let me add that the remembrance of the long and honourable labours of my late father, Dr. Olinthus Gregory, our honorary member, in connection with the scientific branches of the army, as Professor of Mathematics in the Royal Military Academy, my own early associations and subsequent friendship with many of his pupils, and the fact of my having served for some time as a civil member of the Ordnance Select Committee, have all contributed to the desire to call your attention, more particularly, to the application of Engineering to the purposes of National Defence.

On the 25th of November, 1851, a Paper was read at this Institution "On the Application of Machinery to the Manufacture of Rotating Fire-arms," by Colonel Samuel Colt, of the United States, Assoc. Inst. C.E. The Paper claimed for the machinery used, the advantage of cheap production of the weapons in large quantities, and such uniformity in the various parts, that "when a new piece is required, a duplicate can be supplied with greater accuracy," while "in active service a number of complete arms may be readily made up from portions of broken ones." In 1852, the first manufactory in England for the construction of arms on this principle was erected at Thames Bank, under the direction of our Honorary Secretary, Mr. Charles Manby, M. Inst. C.E., and subsequently a manufactory was erected by Messrs. Dean and Adams, which in later years passed into the hands of other companies; but prior to this time the construction of fire-arms was really carried on by small manufacturers, who each made only one separate part, one for locks, one for barrels, one for bayonets, &c., the gunmaker being, in fact, little more than a setter up; and the Government, after obtaining by contract the separate parts of their muskets, excepting barrels and some small parts, from separate manufacturers, put them together at their own works at Enfield.

In 1853, Mr. John Anderson, M. Inst. C.E., Engineer to the Board of Ordnance, proposed the construction and equipment of a Government manufactory, in which, by the use of complete machinery, all the processes for the production of small-arms should be carried on successively to completion. In 1854 the subject was considered by a select committee of the House of Commons, and the adoption of machinery, as recommended by Mr. Anderson, was advocated by Mr. Jos. Whitworth, M. Inst. C.E., Mr. James Nasmyth, General Tulloh, R.A., and other Officers and Engineers; and, in spite of the views of those whose habits or prejudices led them to oppose a new system, the committee recommended a partial trial, which issued in the establishment of the present Small-arm Factory at Enfield.

This new factory, stocked with improved machinery, founded on that already in use in the United States Arsenals at Springfield and Harper's Ferry, and made partly in America and partly in England, was set to work in January, 1857, under the direction of Colonel Manley Dixon, R.A., the present Superintendent of Small Arm Factories, in the construction of small-arms generally, but particularly of the Enfield rifle of the pattern of 1853, which, with trifling modifications, is the long rifle now used in our army, where not superseded by the Snider breech-loader. The machines used at Enfield are to a great extent varieties of copying-machines, in which a standard model is reproduced by a revolving cutter, in wood or metal as the case may require. The different parts, as

produced, are checked with templates and gauges, and finally the finished parts, stock, lock, barrel, bands, bayonet, plates, screws, &c., find their way in numbers to an "assembler," who, furnished with a screwdriver and a chisel, takes the parts up indiscriminately, and puts them together; and so entirely interchangeable are the parts found to be, that a payment of 3*d*·29 for each rifle put together gives the workman wages of about 50*s*. per week.

The long Enfield rifle consists of 53 parts, and passes through about 740 processes of manufacture. These processes are multiplied so as to simplify each operation, to divide the labour, and to require mostly only a cheap class of workmen. All parts, including the stock, are issued for repair in a finished state, and any damaged part in a rifle in use can at once be replaced by a corresponding part without any fitting.

Up to the present time the Government has had no contract for interchangeable arms, excepting one for 30,000 with the London Armoury Company. The Birmingham Small-arms Company has, however, lately made interchangeable short rifles for the Turkish Government. The cost of non-interchangeable long Enfield rifles with bayonets, under a contract made in 1859, was £2. 18*s*. 6*d*. each, to which must be added the cost of the stock 2*s*. 6*d*., and viewing expenses 3*s*., bringing the total cost to £3. 4*s*. 0*d*. each. It is stated that the average cost of the long Enfield rifles made at the Government Factory, including an allowance of 5 per cent. on the cost of buildings and machinery, for depreciation, has averaged about £2. each. In 1859 a contract was entered into for short Enfield rifles, which, complete, and including stocks and viewing expenses, cost £4. 14*s*. 0*d*. each. The cost of subsequently producing the same weapon at Enfield is stated to be £2. 14*s*. 0*d*. each. Neither interest on capital nor profit are included in the Government estimates here quoted.

It has been estimated that the improvement arising from the accurate work produced by good machinery, coupled with that arising from better ammunition, has resulted in reducing by 50 per cent. the mean deviation in rifle shooting. The old smooth-bore musket was considered to make good practice if, at 100 yards, 75 shots in 100 hit a target 6 feet square. With the present service rifle and ammunition, 100 shots can, at the same range, be placed in a space of 6 inches.

From January 1857 to December 26th, 1867, the total number of new arms made at Enfield was 616,828. The number of arms converted to breech-loaders on Snider's plan up to the same date, was 175,550. On April 1st, 1866, an order was sent to Enfield to prepare for the conversion to breech-loaders of 40,000 arms; on July 1st this order was enlarged to 100,000; between July and September, 10,000 converted breech-loaders had been sent to

Canada, and by April 1st, 1867, the whole 100,000 had been supplied. The cost of the alteration of old machines and the supply of new ones for the purpose of the conversion, has nearly reached £10,000, which, divided over 200,000 arms, would come to 1*s.* each. The cost of converting to the Snider breech-loader, including the above sum and depreciation on buildings and plant, is said to be about 16*s.* 3*d.* per arm. With the present machinery, Enfield is capable of turning out about 130,000 new arms annually.

It is said that even now the Enfield factory stands alone in England, and it is believed, in Europe, in the fact that every part of the arm produced there, from first to last, is made on the premises.

The advantages claimed for this central Government establishment are, that it prevents the country from being dependent for arms on private factories, that it maintains a standard of excellence, and can afford to develope the best mechanical improvements, for insuring accuracy, interchangeability, and cheapness. It must be admitted that this establishment has well fulfilled its promise; it has shown great and elastic powers of production; it turns out arms which have the great merit of interchangeability, and which, for soundness and excellence of work, cannot be equalled by the military arms of any other country; and it has, although only by slow degrees, led to the adoption, by a portion of the gun-making trade, of the system of concentration and of copying-machinery.

The Crimean war has given the greatest impulse in modern times to changes in the material of war and the means of defence. Roused from a long interval of repose, undisturbed by any great war, the public interest was at once directed to every measure which was proposed to increase our power for offence or for defence. During the years 1854 and 1855 the Government were besieged by inventors, and the Ordnance Select Committee, to whom their inventions were referred, had often to consider and report on twenty or thirty projects in each week. As might be supposed, a large number of these schemes were wild and impracticable; ungovernable torpedoes and submarine rams, vied with balloons which were to carry shells of tons in weight; ships, in the fore-part of which were to be framed guns of 100 feet long, were to be fitted with a moveable stern for carrying ammunition, and which was to be detached like the limber from a field gun, while the ships of the enemy were to be burnt with naphtha floating on the sea around them. But amidst much that was useless, many practical men were bringing their minds to bear on the great changes which applied mechanics might work out; and if it be no matter of surprise that some of the most valuable propositions came from

Engineers, it is due to those Officers of the Government whose departments came officially under my notice, to bear my testimony to the zeal and intelligence with which they applied themselves to the public service. While the Select Committee fairly and honestly weighed all propositions laid before them, the officers of the gun factory, the carriage factory, the laboratory, and other establishments, were actively employed in the introduction of new machinery, and in many improvements of great and permanent value, with which, then or since, the names of Generals St. George, Lefroy, and Tulloh, Colonels Wilmot, Boxer, Askwith, Dixon, Campbell, and Clarke, and Messrs. Abel, Anderson, Fraser, and others, have become honourably connected.

I will not attempt to follow out all the improvements to which that period gave rise, but will refer shortly to those most connected with our profession, viz., the production of heavy armour plates and large guns, with their consequent results.

While suggestions had been made and partial experiments tried with a view to the use of iron for defensive purposes, prior to the Crimean war, the credit of the first great trial of a practical nature is due to the Emperor of the French, who built three floating batteries cased with thick iron plates, which were engaged in the attack of the Allies on Kinburn, on October 17th, 1855. These batteries were exposed, unsupported, to a heavy fire at a range of 700 yards for about three hours, and although some casualties occurred from shot and shell entering the large old-fashioned port-holes, the vessels received very little injury. From this date the public attention was drawn more closely to the protection of ships of war by armour plating, and various experiments were made in this country, among which were the trials, towards the end of 1858, of the 'Meteor' and 'Erebus,' iron-cased floating batteries, and of an iron shield fixed to the side of the 'Alfred,' against which, for the first time, the powers of rifled ordnance were brought to bear.

It soon, however, became apparent that the subject of the use of iron for this novel purpose was so complicated by considerations of a mechanical character as to demand a more searching technical investigation than it could receive at the hands of purely military or naval authorities; and at the end of 1860 the Government determined to submit the whole matter to the investigation of a mixed Special Committee, which was appointed in January, 1861.

This Committee consisted of six members:—Sir John Hay (Chairman) representing the Navy, Major Jervois, the Royal Engineers, and Colonel Henderson, the Royal Artillery; and to these were added three members whose qualifications were of a more technical character, viz., the eminent metallurgist Dr. Percy, F.R.S.,

and two of our own profession—Dr. Fairbairn, M. Inst. C.E., and Dr. Pole, M. Inst. C.E., whose names are too well known in this room to render necessary any remark on their qualifications for the investigation in question.

The first step taken by the Committee was to collect, by oral evidence, the opinions of a great number of engineers and others practically acquainted with the manufacture and use of ironwork; and the great diversity of the views thus gathered showed the obscurity in which this novel application of material was involved.

The Committee then commenced their experiments, beginning with trials of simple iron plates of various sizes and thickness, and manufactured in different ways, and they arrived early at certain general deductions on points which had previously been uncertain; for example, they reported that out of many varieties of material tried the best for resisting shot was wrought iron;—that this should be of the softest and toughest possible quality, any hardness or steely character being very prejudicial;—that, *cæteris paribus*, the resisting power, up to a certain limit, varied nearly as the square of the thickness;—that corrugations, bosses, or irregularities of surface were disadvantageous, plain surfaces being best;—and that the plates should be as large, and with as few joints as possible.

The Committee further proceeded to examine, and test by actual trial, various constructions of iron defences, both for ships and for land fortifications, the former however receiving their principal attention. This work occupied them for more than three years, during which time a great number of experimental targets were made, on a great variety of principles, and were thoroughly tested with artillery at Shoeburyness.

These trials, on so thoroughly practical a scale, led to experience of great value, not only as to the strength and capability of the material generally to resist shot from certain guns, but also as to the modes of fastening, the effect of various kinds of backing, and the general principles which should guide iron defensive construction. But perhaps the most valuable result of the Committee's labours, or at any rate, the result most interesting in an engineering point of view, was the great improvement effected through their means in the manufacture of iron in large masses. The Committee from the first adopted the principle of making all their trials and results open to the inspection of all parties legitimately interested in the subject. The makers of iron plates were especially invited to witness the experiments, and to study the results produced, being afforded at the same time the benefit of all the information in the Committee's possession which could throw light on the subject. Independently of the public satisfaction given by this open system, which, I believe, has been subsequently followed in other ordnance experiments, these opportunities were of the greatest use to the iron-

makers, for by no other means could they have obtained such complete insight into the nature of the problems to be solved, and the conditions necessary for their solution.

The iron-makers availed themselves willingly of these opportunities, and the result was strikingly marked in the improvement effected.

When the Committee began their labours, the manufacture of armour plates had only been attempted by one or two makers, and even in their hands was little more than tentative; the quality was very uncertain, and no great reliance could be placed on the resisting power of any plates above three inches thick. But during three years' experience, many excellent makers had come into the field; the general average of quality became greatly improved and much more certain, and plates 5 in. and $5\frac{1}{2}$ in. thick could be produced with their full resisting power.

In the middle of 1864, the Iron Plate Committee was dissolved, and their functions re-transferred to the military and naval authorities. I cannot but think this step to have been injudicious; for although doubtless the Government of the day thought that the question had arrived at such a stage of development as no longer to require special technical treatment, yet they omitted, I think, the important consideration that the comparative question between guns and iron defences was, then at least, in a high degree progressive, and that, if improvement was to go on, the technical treatment of the subject must still be necessary; and experience has shown this to be true.

The Committee have left behind them full records of everything they did, containing, in four large volumes of Reports and Proceedings, a mass of information of great interest and value, and forming a compendium of almost all that was then known on the subject. It is to be regretted that these volumes are not published. I find it on record in our correspondence, that one of the members of the Committee, Dr. Pole, obtained the special permission of the Government to give to this Institution a summary of the contents of these volumes, and I take the opportunity of reminding that gentleman that his undertaking to that effect has not yet been fulfilled.

The attention of the Iron Plate Committee was principally directed to plates to be applied to ships: recent circumstances have led to the temporary re-appointment of a Government committee on iron plates, similarly constituted to the last, and comprising the same civil members; and it is to be hoped that their labours may not be prematurely checked, but that they may be allowed to pursue their investigations on the application of iron plates to land forts, so far as to afford safe data to our Royal Engineers, and to prevent the serious evils which might result from

the large application of iron to our Fortifications on any system which had not been fully investigated, and thoroughly tested. I also venture to submit that the hands of the Committee would be strengthened by the addition of a naval architect experienced in the building of armour-clad ships.

During the last few years the size and thickness of iron plates have greatly increased. The plates of the 'Warrior,' constructed in 1861, were 4½ inches thick; those of the 'Bellerophon' are 6 inches thick; while the 'Hercules' has plates of 8 inches, and 9 inches thick at the water-line. In France, the plates used for the navy have been increased to a thickness of 15 centimetres, or 6 inches, and the 'Marengo' and the 'Ocean' will have at the water-line plates of a thickness of 20 centimetres, or nearly 8 inches. A wrought-iron plate, 14 feet long and 6 feet 6 inches wide, and 15 inches thick, has been prepared for trial at Shoeburyness. Some of the principal English manufacturers (Messrs. J. Brown and Co., C. Cammell and Co., and the Millwall Iron Company) now offer to roll plates about 20 feet long, 6 feet wide, and 15 inches thick; but it may be doubted whether plates of such thickness and size can at present be so perfectly manufactured as to give their full proportionate resistance: the production of thoroughly sound and uniform plates of large size, 10 inches thick, may, however, I believe, be regarded as an accomplished fact.

Concurrently with the production of iron plates for purposes of protection there has been a great increase in the size and destructive power of Ordnance. Some of the earliest guns known were compound, or built guns. In the Royal Military Repository at Woolwich is one of the time of Henry VI. (1422 to 1461), composed of two circles of longitudinal iron bars, imperfectly welded, and close hooped with iron rings, with a bronze powder-chamber inserted in the breech:—indeed for guns of any size a built gun was a necessity at a period when the manipulation of metals in large masses was a rare and difficult operation. The great bombards at Edinburgh and Ghent, closely similar to one another in design, and those of English manufacture at Mont St. Michel, are notable instances of large built guns, which, however, could probably not have stood one full charge of powder of modern strength.

The development of art in the fifteenth century, which revived large bronze castings for ornamental purposes, led, perhaps, to the use of bronze for guns. In the year 1543, in the reign of Henry VIII., Ralph Hogge is stated to have cast, at Buckstead, in Sussex, the first cast-iron guns used in England, but it was not until a much later period that cast-iron guns were largely used in England, or at all on the Continent. For many years before the

Crimean war, brass and iron guns had been made with very little change of form; but when public opinion was drawn to the application of mechanical improvements to the production of guns of great size and strength, clever designs were brought forward by so many that I will not attempt here to give even a list, much less to assign to each its due proportion of merit; but the large wrought-iron "Horsfall gun" of the Mersey Company and the monster mortar of Mr. Mallet may be cited as two remarkable examples. The "Horsfall" was a smooth-bore gun, in one piece, weighing 21½ tons, and having a calibre of 13 inches; and it is now mounted at Tilbury Fort. Mr. Mallet's mortars were compound, weighing 41 tons, with a calibre of 36 inches, from one of which, with a charge of 70 lbs. of powder, a shell weighing 2,395 lbs. was thrown 2,759 yards, burying itself 8 yards in the ground on its fall. The limited practice with this mortar was interrupted by the fracture of a tie-bolt; but it is greatly to be regretted that no further experiments have been made with it, or with the second piece, which has never been fired.

The remembrance of the discussions held in this room will recall the names of Sir W. Armstrong, M. Inst. C.E., Mr. Whitworth, M. Inst. C.E., Mr. R. Mallet, M. Inst. C.E., Mr. Longridge, M. Inst. C.E., Captain Blakely, R.A., and others, as having either investigated the scientific principles which should direct the construction of great guns, or applied those principles to various forms of construction. You will all remember that in 1860 breech-loading rifled guns were the order of the day, and that neither brass nor cast iron, as materials, were considered to fulfil the necessary conditions. The designs which had earned the greatest consideration, both from the Government and the Public, had been produced by those two distinguished members of our body, Sir William Armstrong and Mr. Whitworth; and as far as the construction of the guns was then concerned, the leading points of difference were, that while the Armstrong gun was built up of several rings or tubes of coiled wrought iron shrunk over one another, and over a steel lining, with small grooves to take a soft coated projectile, the Whitworth gun was built up of tubes of mild steel, forced with a taper over one another, and over a steel lining, the bore being polygonal, with a hard mechanically-fitting projectile.

The details of both systems were subsequently more or less changed, and in January, 1863, a special mixed Committee was appointed to make full experiments, and to investigate, with two calibres, viz.: 12 pounders and 70 pounders, the comparative merits in construction, endurance, range and accuracy, and in fact, in all the qualities which a gun should possess. The investigation was completed in April, 1865: the information collected showed, in both systems, results as to structural strength, and

efficacy and accuracy of fire, which had not been previously attained; and while it was not in all respects conclusive as to the comparative merits of the guns, it pointed out more prominently than ever the perfection to which artillery might be brought by the application of Engineering skill.

In 1859, Sir William Armstrong was appointed Superintendent of the Royal Gun Factories, and, assisted by Mr. Anderson, established the new workshops for the construction of compound guns, which were fitted up with machinery of great power and accuracy, specially designed for dealing with large masses of metal, and for ensuring precision of manufacture in putting together the various parts of the Armstrong gun, which practically became the gun of the service.

In 1863, Sir William Armstrong resigned his office, which has since been filled by Colonel Campbell, R.A., with Mr. R. Fraser, M. Inst. C.E., as his executive assistant.

Irrespective of breech-loading, which has been abandoned in this country for heavy guns, and of rifling, in which the original mode has been to a great extent superseded by larger grooves to guide soft metal studs fixed on a hard metal projectile, the gun now generally manufactured for the service has undergone considerable structural changes, the most material one being the diminution of the number of parts, and the substitution of outer coils of fibrous Staffordshire iron for coils of the best Yorkshire iron, tough steel being still maintained for the lining, as best resisting surface wear. In the former type of gun, there was a forged breech-piece over the breech end of the steel lining tube, and, according to the size of the gun, a greater or less number of coiled tubes, carefully and successively fitted on. The pattern at present in use for all guns consists of only four pieces:—viz., 1st, the steel barrel or lining; 2nd, a coiled tube over the barrel, extending from the muzzle nearly to the trunnions; 3rd, the breech coil, consisting of three coils in alternate directions, welded together, with a trunnion piece welded on, the whole piece shrunk on over the breech of the barrel, and lapping over the front coil; 4th, the cascable. It is considered by the present authorities that the diminution in number of parts leaves the gun less liable to injury by accident and less dependent upon perfection in manufacture, and that practically an equal amount of strength is obtained; while it is held that a fibrous iron is to be preferred as more workable for coils, and as giving out its greatest strain over a greater distance than the best Yorkshire iron, which, while stronger statically, is considered not to yield so far before fracture. It is stated that this change has diminished the cost of production by 35 or 40 per cent.

The heaviest projectile thrown by any gun in the service prior to 1854, was the 200 lb. shell of the 13-inch mortar.

The largest Armstrong gun hitherto constructed is an experimental one, which has a calibre of 13·1 inches, weighs 23 tons, and throws a shell of 600 lbs.

It is intended that future 12 inch guns shall have a weight of 25 tons.

The 11 inch gun lately constructed weighs 23 tons, and the weight of the several parts are as follows:—The steel barrel, 5 tons 5 cwt. in the rough, 2 tons 16 cwt. finished; the muzzle coil, 2 tons 15 cwt. in the rough, 1 ton 16 cwt. finished; the trunnion and breech coil, 22 tons 6 cwt. in the rough, 17 tons 17 cwt. finished; the cascable 14 cwt. in the rough, 11 cwt. finished.

Two guns of Mr. Whitworth's, of 9 inch calibre, and weighing 15 tons, are about to be delivered for trial.

Prior to the mechanical improvements which have led up to the present rifled guns, the greatest distance to which a projectile was ever thrown from a smooth bore gun was not much over 6,000 yards, and the limit of bombarding range at high elevations, with the 13-inch mortar, was 4,500 yards. With the modern ordnance projectiles have been thrown, with greater precision, to a range exceeding 10,000 yards: the guns of the service make good practice at 6,600 yards; in fact, much better practice than was formerly attainable at 3,000 yards.

At 1,000 yards the mean error of range of round shot from smooth bores may be taken as 43 yards, and that of rifled shot 19 yards; the mean error of direction (referred to the mean direction of all the shot), with round shot may be taken as 4·1 yards, and with rifled shot as 0·8 yard. At 2,000 yards the mean error of range of round shot may be taken as 60 yards, and that of rifled shot 21 yards; the mean error of direction with round shot 10 yards, and with rifled shot 21 yards. In other words, (the accuracy being inversely as the products of the errors,) the rifled gun is, in one case more than eleven times, and in the other, more than thirteen times as accurate as the smooth bore.

I have alluded to the structure and effects of British modern ordnance as giving another marked example of the advantage which has followed the application of Engineering skill, and the production of machines of special power, accuracy, and fitness, with which the names of Mr. Nasmyth, Mr. Whitworth, and Sir W. Armstrong are enduringly associated; and although I feel that a detailed comparison with the ordnance of other countries would perhaps be out of place, I may be allowed to express my belief that great as have been the advances made in the manufacture of heavy ordnance in France, in Prussia, and in the United States, neither have attained the certainty, the economy, or the perfection, of the productions of British Factories. But all our improvements will be of little avail in time of need, until smooth bores are much more largely replaced

by rifled-guns. Meanwhile, for all practical purposes, we are almost unarmed in many of our so-called Defences, at home and abroad.

While such important changes have been effected in modern Ordnance, the advance recently made in Naval Construction is alike remarkable, and would have been equally impossible without the resources of modern Engineering.

Without attempting to trace the progress from wooden to iron ships, or all the steps by which our naval architects have passed from the earliest to the most recent types of armour-clad ships, I propose to illustrate the general results by some comparisons between the structures of the 'Warrior' and the 'Hercules' as ships of 1860 and of the present period respectively. The 'Warrior,' of 6,109 tons, and 1,250 H.P.. has armour-plating $4\frac{1}{2}$ inches thick, with teak backing of 18 inches, and an inner skin of $\frac{9}{16}$ths of an inch, the whole being backed by vertical frames, 10 inches deep, and about 2 feet apart. A length of 213 feet in the middle part of the ship is plated, and upwards of 80 feet at each end unprotected. The armour-plating of the mid-ship battery extends from 6 feet 3 inches below the load line to the height of the upper deck, while the ends of the battery are protected by transverse armour-plated bulkheads. The unprotected ends are divided into water-tight compartments, as a provision against the danger of shot-holes near the water-line; but there is no protection to the rudder-head and steering apparatus. The bow and stern guns on the upper deck are unprotected; and the only guns that can be fought under cover, are on the broadside, where they cannot be trained through an arc of more than 50° or 60°, a serious inconvenience with a vessel whose length of 380 feet is not favourable to rapid manœuvring.

The objections raised to a system which left so much of the ship unprotected, led, in ships of the 'Agincourt' class, and the converted wooden line-of-battle ships, to the adoption of complete armour-plating for the whole length of the ship, from the upper deck to a few feet below the water line; but as the increasing power of guns made it necessary that armour-plating, to be effectual, should have greater thickness and weight, it became evident that to continue complete protection would involve such increase in the size of a ship as to render her almost useless for manœuvring. These considerations led to the introduction of the arrangement now adopted for the broadside ships of our navy, which provides a protected battery amidships, shut in by armour-plated bulkheads, and a belt of armour for the whole length in the neighbourhood of the water-line. By this means, in addition to the battery, protection is given to the neighbourhood of the whole water-line, to the engines and boilers, and to the rudder-head and steering apparatus. The first example of this distribution of armour was its

application, in 1862, in the conversion of the 'Enterprise,' a wooden sloop, from the designs of Mr. Reed, chief constructor to the Royal Navy.

The 'Hercules,' of 5,226 tons and 1,200 HP., has armour-plating arranged on the same principle, with the important addition that besides the central battery on the main deck, 73 feet long, there are protected batteries, on the main deck, at the bow and stern, 20 feet and 8 feet long respectively. The lower edge of the armour is 6 feet below the load line; on the batteries it extends up to the upper deck, and along the belt it ends at the main deck. The armour about the water-line is 9 inches thick, thence up to the port sill of the battery deck it is 8 inches, and the remainder 6 inches. The teak backing varies from 10 to 12 inches in thickness, and the skin plating is in two thicknesses of $\frac{3}{4}$-inch each. The vertical frames behind the armour are 10 inches deep and 2 feet apart, with horizontal girders of about the same size, and at equal distances, placed outside the skin plating. Within this structure is a second wood backing, supported by a second series of skin plates and vertical frames, from the lower deck down to the lower edge of the armour. Before and abaft the central battery, there is iron plating below the planking of the main deck, as a protection from vertical fire where the armour only extends a few feet above the load-line.

The sides of this ship are recessed before and abaft the central battery, so that by means of embrasures in the armour-plated bulkheads, the foremost and aftermost gun on each broadside can be traversed on turntables, so as to fire at an angle of 15° with the line of the keel, while that line is commanded by the guns in the bow and stern batteries. The 'Hercules' is 8 inches wider in beam than the 'Warrior,' but 55 feet shorter, and of 883 tons less burthen. She will carry a smaller number of guns, but of much greater weight, so that in the particulars above given she has the elements of much greater power, both for offence and defence, while in the former quality she is, perhaps, inferior in some respects to a type of ship now on the stocks, such as the 'Invincible,' which has an upper-deck battery, to carry four guns, each of which can be fired either from the broadside or fore and aft.

To the proper use of armour-plating, iron ships have become a necessary condition; and in their construction the principles worked out by our late Vice-President, Mr. I. K. Brunel, by which the different parts of an iron ship are made to contribute to its strength, have become of great value. Mr. Scott Russell, the late Mr. Miller, Mr. R. Napier, Mr. Samuda, and others of our Members, have borne their share in modern improvements in iron shipbuilding, and with those naval architects who are not yet Members of our body, we claim professional brotherhood. No Member

of this Institution is likely to overlook the increased power which our Navy has derived from the improvements in marine engines, in which Messrs. Maudslay and Field, Penn, Seaward, Rennie, Lloyd, Stephenson, Ravenhill, Humphreys, and others of our Members have taken so active a part; and the screw propeller was first practically introduced and subsequently brought to its present use by the labours of Members of our body.

Our Navy now possesses thirty-one iron-clad ships, and eight more are on the stocks, four of the existing ships being furnished with turrets, which are to be supplied to two of the new ones. Admitting that this number represents a formidable force, and that in structural qualities our recent ships are excellent in design and construction, and superior to those of other countries, it must be remembered that many of our ships are of doubtful strength; and you will probably be surprised to hear that the sum devoted to the construction of new iron-clad ships for the current year does not reach £900,000, being less than one-twelfth of the vote for the Navy, and barely sufficient to build three iron-clad frigates. If an Iron-clad Fleet be proper and necessary, surely this fact merits the gravest consideration.

In the construction or improvement of our existing Fortifications, it must be admitted that our profession can claim to have contributed comparatively but little. Our Past-Presidents, Mr. Hawkshaw and Mr. M'Clean, have been intrusted with the construction of the foundations for forts at Spithead and Plymouth, of which we hope in due time to receive the records. The use of iron plates for land defences has at present been little more than experimental; various mechanical appliances are however in contemplation or under trial, and iron armour is proposed for many of the sea and river forts, to several of which turrets also will be applied. It cannot be denied that if much money had been laid out on works of this character with the information of only a few years ago, most of that expense would have been wasted; at the same time it may be suggested that improvements may come too late, if they are delayed in hopes of arriving at perfection.

Any notice of the principal applications of Engineering to the purposes of National Defence would be incomplete without some reference to Railways, which have always been expected to have an important bearing on modern warfare. They were admitted to be of great use in the movement and concentration of troops in the war in Lombardy in 1859; and in the German war of 1866 the Prussian government organized a special corps consisting of workmen and railway servants, under the direction of engineers and traffic officers, of which a division was attached to each "corps

d'armée," to act, assisted by a military escort, in advance of the army, to repair any damages effected by a retreating enemy, to work lines occupied by the army, and, in case of retreat, to destroy lines in their rear.

Lieut. Hozier, in his admirable account of the Seven Weeks' War, admits the value of improved roads and railways in shortening the duration of campaigns, and especially in facilitating the transport of provisions, stores, and a siege train, and in relieving soldiers of heavy loads; but he considers that the power of railways for the transport of troops has been over-estimated; and that, in an enemy's country, railways have been proved to be of no use for the transport of the troops of the invader, during his advance, as the defending army breaks them up, and they cannot be repaired quickly enough. But, even independently of hostile obstructions, he says that experience proves that 10,000 men, equipped for the field, is the most that can be calculated upon to be moved per day, on a single railway; that when the Prussians were concentrating their army for the invasion of Saxony, it was rarely possible to send more than twelve trains a day, and that it required nearly ten days to move a corps d'armée of 30,000 men with all its "train" and baggage; and that even when the Austrian army was in retreat on Vienna, with little "train," and no baggage, it took them about six days to move 40,000 men.

I cannot but think that Mr. Hozier's views of the carrying capacity of railways might have been modified by the knowledge of what is done, on the volunteer field days, in this country; while his opinions on the uselessness of railways in an enemy's country, are apparently inconsistent with the experience of the last American war.

In that war railways and steamboats were found of inestimable advantage: the Reports of General Parsons, chief of rail and river transportation for the United States, show that he considered that the application of steam to transport had modified the art of war as much as the pursuits of peace, and he stated, in 1865, as the result of his experience, that "it is now practicable, on twenty-four hours' notice, to embark (by railway) at Boston or Baltimore a larger army than that with which Napoleon won some of his most decisive victories, and landing it within three days at Cairo, 1,200 miles distant, there embark it on transports, and within four days' more time, disembark it at New Orleans, 1,000 miles farther." In January, 1865, in the depth of a severe winter, the 23rd army corps was wanted for General Grant's operations before Richmond; after four or five days' notice, this force, consisting of 20,000 men, with all its artillery, and over 1,000 animals, was started from the Tennessee River, and moved nearly 1,400 miles in an average time not exceeding eleven days. The distance was about equally

divided between water and railway transport, along rivers obstructed by fog and ice, and over mountains during violent snow-storms; with various interruptions, including thirty hours' detention from fog in the river, and, at one point, the unexpected delay of transferring the troops to boats of a smaller class; the railroad, meanwhile, being in the bad condition unavoidable in the severe winters of North America. Within seventeen days from the embarkation of the first troops on the Tennessee, General Parsons had the satisfaction of seeing the army quietly encamped on the banks of the Potomac, as fresh as when they started from the Tennessee.

During the war, 611 miles of railway in Virginia, Maryland, and Pennsylvania, 293 miles in North Carolina, and 1,201 miles in the military division of the Mississippi, giving a total of 2,105 miles, were more or less occupied by the United States authorities as military railways, under the direction of General M'Callum; the government staff carrying on all the working of these lines, and repairs of works and rolling stock, and to some extent the rolling of rails, and the construction of new lines. At an early period a number of workmen, under competent engineers and foremen, were formed into a "construction corps," and stationed in detachments along any railway exposed to hostile attack, and stores were established, at intervals, to furnish the necessary supplies of rails, fittings, sleepers, and bridge timber. This corps became at last very experienced in the work of repairing damage. General M'Callum's reports state that the Rappahannock River Bridge, 625 feet long and 35 feet high, was rebuilt in 19 working hours; that Potomac Creek Bridge, 414 feet long and 82 feet high, was built in 40 working hours; that Chattahoochee Bridge, 780 feet long and 92 feet high, was completed in $4\frac{1}{2}$ days; that between Tunnel Hill and Resaca 25 miles of permanent way and 230 feet of bridges were reconstructed in $7\frac{1}{2}$ days; and near Big Shanty, $35\frac{1}{2}$ miles of permanent way and 455 feet of bridges in 13 days. The last of these remarkable operations took place on the line by which General Sherman was connected with his base, in his advance from Chattanooga to Atlanta; and, that the Military Railway Department, almost entirely through a hostile country, should have kept pace with the march of General Sherman, constructing and reconstructing the road in his rear, and ultimately have maintained the supplies of an army of 100,000 men and 60,000 animals from a base 360 miles distant, along a single line, exposed at all times to the attacks of an active and resolute enemy, is indeed a wonderful example of forethought, energy, patience, and watchfulness.

In our own country there can be no doubt that our railway system is one of our greatest elements of strength for national defence, while, in case of need, the skilled labour usually employed in peaceful constructions might be employed in works for our own

protection, and for the obstruction of an enemy. In the year 1860 a proposition was addressed by Mr. C. Manby to Mr. Sydney Herbert, Secretary of State for War, offering the services of several members of this Institution for the formation of a Volunteer Corps, which should be ready for such work. The offer was favourably received, but no action was taken upon it until the year 1864, when General McMurdo, then Inspector General of Volunteers, penetrated with the importance of the subject, gave it his best attention; Mr. McClean, our President at that time, and other members of the Council, became warmly interested in it, and ultimately, in January, 1865, with the support of the Marquis of Salisbury, Lord Lieutenant of Middlesex, Earl de Grey, as Secretary of State for War, recommended to Her Majesty the establishment of the "Engineer and Railway Volunteer Staff Corps," "for directing the application of skilled labour, and of railway transport, to the purposes of national defence, and for preparing, in time of peace, a system on which such duties should be conducted." This corps, commanded by our Past-President, Mr. Bidder, consists of officers only, who must be Civil Engineers, Contractors, or Railway Officers. Its duties comprise the preparation, for the use of the Government, of reports on the railway transport of troops and their supplies, on the destruction and reconstruction of railways, the improvement of natural obstacles, and the making of artificial ones to impede the landing or advance of an invading force, and on topographical particulars connected with these subjects. These reports are confidential, but I may mention that they already contain much practical information with which the officers of the Government have been pleased to express great satisfaction, and that the calculations which have been made, in their preparation, by some of the most experienced railway managers, show that the completeness and the resources of our railway system would enable the whole regular and irregular army of the country to be moved upon any required lines of defence within a few days.

Before concluding, I ask your indulgence for a few suggestions with regard to the future.

And first I submit, that, however complete and efficient those Government establishments may be which produce our iron ships, our guns, and our rifles, and admitting the importance of maintaining their efficiency, it would be a mistake to extend their use so far as to cripple individual enterprise, and, by excluding all competition from without, to leave them no rivals now, and no assistants in time of need. By such competition many valuable inventions have been produced already, and may be expected hereafter; and the encouragement which Government can give by the

employment of the best private manufactories will stimulate improvement, distribute and extend the employment of labour, increase the productive energies of the country, and enlarge their own sources of supply, to any extent which sudden emergency may require.

In the next place, it must occur to many, that while great defensive works have been carried out at Portsmouth and Plymouth, some of our other dockyards and arsenals are left comparatively unprotected, as well as the Thames, the Mersey, the Clyde, the Tyne, and other rivers leading to rich towns, docks, and shipping, and to many great establishments which are or might be made supplementary dockyards and arsenals, and the destruction of which, apart from any direct injury to the public service, would be a terrible public calamity. The Thames, especially, offers the greatest temptation to any hostile fleet, which, even for a few days, might gain possession of the narrow seas.

And, if Forts are to be built at any of these places, may I suggest the inquiry, whether it is necessary that they should be calculated to resist a long siege, and be of such size as to absorb for their defence a large number of men, or whether, as a general rule, it would be sufficient for them to be of small size, and capable of offering resistance to a sudden attack? I do not presume to give an opinion upon this subject, but the great power of our railway system, by which a large force not only of soldiers, but of labourers, might be concentrated rapidly upon any given point, would seem to indicate that any hostile attack, unless made with overwhelming numbers, to be successful, must be so in a few days.

Our Navy for some years past has been in a transition state, but perhaps the time may have arrived when the classification of ships for all the various services may be considered; and if so it may be desirable to settle in the first instance the type best suited for our coast defence; and when this is done, no time need be lost in producing such a number of that type as would strengthen us at the most vital points, and give us the mastery along our own shores. But the instinctive feelings of every Englishman call for the establishment and maintenance of a Navy sufficiently strong to defend not only our Coasts, but our Colonies, and our Commerce; and the Government which would set itself at once to answer that call, would, I believe, command the support of the majority of the patriotism and intelligence of this country, and would at the same time bring comfort to thousands of deserving workmen and their families, now suffering in grievous want.

In conclusion, let me express my earnest hope that the future of this Institution may be as useful and as prosperous as its first half-century has been. Our limited vision cannot trace the new paths

which Science may open out, or the new purposes to which Engineers may have to apply the powers of Nature; but I feel assured that this Institution will supply men of character and intellect, equal to every occasion, and who will join in the Defence of our Country, by contributing to her moral, and material greatness, leaving England's future, with reverent confidence, to the Great Source of all Power and all Intelligence.

January 21, 1868.

CHARLES HUTTON GREGORY, President, in the Chair.

The discussion upon the Papers, Nos. 1,178, and 1,176, "On the Victoria Bridges, Pimlico," occupied the whole evening, to the exclusion of any other subject.

January 28, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,167.—"On the Relation of the Fresh-water Floods of Rivers to the Areas and Physical Features of their Basins; and on a Method of Classifying Rivers and Streams, with reference to the Magnitude of their Floods; proposed as a means of facilitating the investigation of the Laws of Drainage."[1] By Lieut.-Colonel Peter Peirce Lyons O'Connell, R.E., Assoc. Inst. C.E.

When water falls in the shape of rain on any solid surface, whence it afterwards flows off, it forms its own drainage vehicle. It produces over that solid surface a certain depth of water with a certain superficial slope or fall towards an outlet; these two conditions, depth and surface slope, being necessary to produce flow. Should the solid surface be at all absorbent, the rain has also to furnish the quantity of water necessary to saturate it. While the drainage vehicle is forming and having its capacity increased, the water is flowing off the surface less rapidly than it falls upon it, and it is only when the time necessary for this preliminary operation of forming its own drainage vehicle has elapsed, that the water flows off from a surface as rapidly as it falls upon it. The time required increases with the linear distance between the upper and lower ends of the surface drained, and with the gentleness of its fall.

All natural surface drainage commences in the manner above described, which, for convenience of reference, will be termed "the first stage of natural surface drainage." It may then be said to be carried on and completed by rills, streams and rivers.

It will be evident from the above remarks respecting "the first stage of natural surface drainage," that, should the rain cease before it has completed its own drainage vehicle, the rate of discharge from the surface upon which it falls will never equal the rate at which the rain has fallen upon it. This is also true of a drainage area or basin, consisting of many such surfaces discharging into natural streams or artificial drains. The larger the basin the

[1] The discussion upon this Paper was taken in conjunction with the succeeding one, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

greater the length of time for which rain must fall, in order that the rate of discharge by stream or river may equal the rate at which the rain falls. Hence it is that streams draining large areas are not subject to sudden floods caused by short smart showers.

An operation similar to that of rain forming its own vehicle of discharge, is performed by every river in its own channel, but this is especially the case with a river flowing through a lake. As long as the lake receives in a given time more water than it discharges, the river may be considered as increasing the capacity of its vehicle of discharge, inasmuch as it is raising the surface of the lake and increasing its rate of discharge. For want of time it does not complete its work. Hence the lake, like the extension of the area of a drainage basin, is a moderator of the flood discharge, resulting from a given rate of rainfall. There are other natural moderators which are more or less effective; viz., a porous, absorbent soil, and the foliage of dense forests, but the latter has apparently the property, in some situations, of increasing the actual amount of rainfall, which counterbalances its effect as a moderator of river floods. Snow may, according as it thaws slowly or rapidly, be a moderator or the reverse.

When a tributary in flood flows into a large main river, the channel of the latter acts very effectively as a moderator; the flood forming on the surface of the main river a wave, the summit of which is constantly being depressed as it travels down the river. The result of this depression is that the river discharges a smaller quantity per second at its mouth than at its junction with its tributary, if the latter is the only one in flood at the time.

Since mere extension of the area of a drainage basin is in itself a moderator, it is evident that if the rate of rainfall diminished as its duration increased, the rate of discharge from a surface receiving rain would vary inversely as the distance between its highest and lowest levels; or, speaking generally, inversely with its area. Even if this be not absolutely correct, it may, for all practical purposes, be assumed to be true. And, as an immediate deduction therefrom, it may be concluded that when rain falls upon steep, retentive, and clear ground, forming a drainage basin, the rate of discharge will approximate more closely to the maximum rate of rainfall the smaller the area of that drainage basin, but that it can never exceed it. The maximum rate of rainfall is thus shown to be a limit to which the rate of discharge approaches, under the favourable circumstances just mentioned, but which it never exceeds, except in extraordinary cases which will be alluded to hereafter, and which are here purposely excluded from consideration.

If a series of natural basins could be found increasing regularly in area, having physical features as to slope, soil, &c., all tending in the same degree to discharge the rain falling on them,

and if the distribution of the rain were the same in all these basins, then doubtless the rate of discharge in floods might be represented graphically by some regular curve, the abscissæ of which would represent the area drained, and the ordinates the flood discharge per second. This curve would be concave to its base, and the tangent at its origin would have a value representing exactly the maximum rate of rainfall. Such, however, are the diversities of physical features in river basins, and in the distribution of rainfall in the world, that the search after the desired series of natural basins possessing exactly similar characteristics would probably be a vain one. This is to be regretted, for rivers small and great might alike be referred to some such curve, and classified as flood dischargers, according as they took up positions near to or distant from the curve.

To supply the place, as a classifier, of this unknown curve, the Author would suggest the use of the common parabola as follows:— Let x, the abscissa of a point in the curve, represent the area in square miles drained by a river; and y, the ordinate of the same point, represent the number of cubic yards discharged per second by that river. Then in the common parabola $y = \mathrm{M} \cdot \sqrt{x}$; where M may be termed the modulus of the river, or of its drainage basin, as a flood producer. When M is large it will indicate that the physical features are such as to slope, soil, total amount and distribution of rainfall, as to give the river and its drainage basin a high place in the classification. When M is small it will, on the contrary, indicate either that but little rain falls on the basin, or that it possesses some of those physical features which tend to moderate floods.

With the view of illustrating how far this method of classifying rivers as flood producers is likely to prove useful, there are subjoined a few facts respecting the Mississippi and its tributaries, extracted from the report on that river prepared by Captain A. A. Humphreys and Lieut. H. L. Abbot, of the Corps of Topographical Engineers of the United States Army.

Name of the River.	Area of its Basin in Square Miles.	Rainfall.		Values of M.
		Annual Fall in Inches.	Quantity Drained off by the River in Inches.	
Main Mississippi	1,244,000	30·4	7·6	49·28
Ohio at Wheeling Bar . . .	25,000	..	..	57·
Ohio at its mouth	214,000	41·5	9·96	56·
Red River	97,000	39·	7·8	26·76
Arkansas and White Rivers .	189,000	29·3	4·395	13·06

It will be seen from this table, that while the number of inches of rain drained off annually by the Main Mississippi and by the Red River are 7·6 and 7·8 respectively, the values of M are 49·28 and 26·76 respectively. This difference is too great to be accounted for by the number of rainy days being greater in the basin of the Red River than in the basin of the Mississippi generally. If, therefore, the proposed method of classification be worthy of adoption, its evident indication of the existence of some flood moderator in the basin of the Red River must be correct; and it will be found that it is so. There is in the Red River, according to the report just referred to, a remarkable raft, "composed of an immense accumulation of drift-logs—some floating, and others so water-logged as to sink, and thus still more effectively block up the channel. . . . . The obstruction of the raft has thrown a large proportion of the water of the river (about three-fourths) through two natural outlets (Dooley's and Red bayou) into Soda lake, affording a navigation around the raft (right bank), which is constantly improving as the action of the water widens and deepens these channels. . . . The range of the river is greatly affected by the raft. Thus at Fort Towson it is some 45 feet, the maximum (January 27, 1843) being 51 feet; at Fulton it is 35 feet; at the head of the raft, 10 feet; at Shreveport, 25 feet; at Alexandria, 47 feet; at the mouth, 45 feet. These numbers illustrate the effect of lakes in moderating floods. The raft also greatly modifies the normal succession of stages in the lower river, by equalizing the flow of the freshets, which are very sudden above the raft."[1]

These extracts sufficiently prove, that the value of M for the Red River ought to have been, as it has been found, low; and tend to show that the proposed method of classification may be usefully, if cautiously, applied. Nothing more can be claimed for it. It is to some extent empirical, and must be set aside whenever any other curve can be shown to suit the purpose better than the common parabola. In the meantime its application may be recommended, and its use will be hereafter further illustrated.

There are certain exceptional cases of river floods, which, not being regulated by the ordinary laws of drainage, must necessarily be excluded from a classification embracing only the usual results of physical causes. Several such cases are recorded by Sir Charles Lyell.[2] The causes assigned for these are landslips or barriers of ice, closing for a time the outlets of valleys, and accumulating large bodies of water, which ultimately burst their barriers, and escape within a few hours. It is also stated,[3] that "a volcano in Lucanas

[1] *Vide* "Report upon the Physics and Hydraulics of the Mississippi River;" &c., pp. 37—39.

[2] *Vide* "Principles of Geology," ninth edition, p. 208, *et seq.*

[3] *Vide* Ibid., p. 501.

(Peru) burst forth the same night (the 28th October, 1746), and such quantities of water descended from the cone that the whole country was overflowed; and in the mountain near Pataz, called Conversiones de Caxamarquilla, three other volcanos burst out, and frightful torrents of water swept down their sides." Inroads of the sea, caused by earthquakes, are of course excluded, as having nothing to do with fresh water floods.

Exceptional floods are also caused by the bursting of artificial reservoirs, by the destruction of bridges originally constructed without sufficient waterway, or of bridges constructed on streams at a period when, the regimen of their beds not being fixed, these were still being raised by accumulations of stones, gravel, or sand. In a case of the kind last mentioned, the waterway of the bridge, although ample at first for the passage of floods, becomes in time too small for the purpose. The bridge then forms an obstruction. It is at length swept away, and the waters, suddenly escaping, produce unusual floods lower down the stream.

There are many small rivers in Southern India, where irrigation reservoirs or tanks are numerous, which were formerly, and to some extent are still, subject to excessive floods, caused by the simultaneous or successive bursting of a series of tanks situated in the same valley.

It is evident that, before any attempt at the classification of rivers or flood dischargers is made, all extraordinary floods similar to those mentioned must be excluded.

It is to be regretted that data sufficiently extensive and accurate for the purpose of testing very rigidly any method of classification have not yet been collected. A compilation has, however, been made, from the Author's knowledge of Indian rivers, and from the statements contained in hydraulic works respecting European and North American rivers. These will be found exhibited in the table appended to this Paper (page 215), and in the diagrams attached to it (Plates 9 and 10).

For the Indian rivers entered in this table the maximum values of M vary from 40 to 302·7. This may, at first sight, appear to be a very wide range; but the fact is, that if examples had been collected from every part of India, the range would have been from M = 0 to M = at least 2,000. The annual amount of rainfall varies within the limits of Hindostan as much as in the whole world, for in parts of Scinde a shower is a rare occurrence. At Hyderabad the annual fall averages 3 inches, and at Kurrachee 8 inches; whereas at Chirrapoonjee, on the south face of the Cossya or Garrows mountains, 530 inches fell, according to Dr. G. Hooker, in six months of 1850, viz., from June to November, and of this 30 inches fell in twenty-four hours. There is nothing to show that these are excessive falls for the locality. The fall of 30 inches in twenty-four

hours is probably below the maximum; for at Madras the fall has exceeded 17 inches in twenty-four hours twice within the last twenty years, whereas the annual fall has not exceeded 89 inches since 1813.

In the few examples given of North American rivers, the value of M varies from 13·06 to 57.

In the examples given of British rivers and streams the value of M varies from ·43 for a stream draining a small piece of meadow land to 37 for the Tyne. The maximum value of M would, it is supposed, be found in some stream in Cumberland or Westmoreland, before it falls into a lake, but it could hardly exceed 120. For by far the greatest portion of the country the value of M cannot exceed 15 or 20.

In the examples given of large European rivers, the values of M vary from 16 for the Seine, deduced from the discharge given by Dupuit,[1] to 74 for the Danube at Pesth, which is somewhat uncertain, and probably too small. The value 67·53 for the Danube at its mouth is trustworthy, being deduced from Sir Charles Hartley's Paper on the Danube.[2] The value of M for the Loire at Pont de Fleurs, 20 miles above Roanne, is 196. The steepness of the hills east and west of the valley of the Upper Loire tend to give a higher value to M; but this is too high to be accounted for, except by the locality being also subject to heavy falls of rain, or sudden melting of snow.

The value of M for the Nile, viz., 11·38, is remarkably low for a river rising so near the equator, showing, what is otherwise known to be true, that but little rain falls in that portion of the interior of Africa where the basin of the Nile is situated. This low value is also partly the result of the lakes and inundated country through which the river flows.

The value of M generally diminishes with the distance of a basin from the equator, just as the annual fall of rain diminishes, and the number of rainy days increases with distance from the equator. Both these rules are general, and liable to important exceptions, the causes of which are now partly understood, and are usually stated, as far as rainfall is concerned, in works on Physical Geography.

These observations being general, and dealing with very wide differences in the value of M, may not at first appear to be of much practical use in an engineering point of view. This arises principally from the areas of country considered being very great. Each engineer may, however, ascertain for himself experimentally the value of M for the district in which he is employed; and,

[1] *Vide* "Études théoriques et pratiques sur le Mouvement des Eaux," deuxième édition, p. 191.

[2] *Vide* Minutes of Proceedings Inst. C.E. vol. xxi., p. 277, *et seq.*

as a general rule, the smaller the district, the less will be the range in the values of M. It is important to observe, however, that whereas, in the case of large rivers, the parabola expressive of the relation between the area drained and the discharge per second may, without sensible error, be supposed to have its apex situated at the origin of the co-ordinates, in the case of small districts this supposition would lead to error. In the latter instance it becomes necessary to ascertain, at least approximately, what is the maximum rate at which rain falls in the district, and to place the origin of the co-ordinates at a point in the curve where the inclination of the tangent to the axis of x shall correctly represent that maximum rate.

The late Major Jacob, when Astronomer in charge of the Madras Observatory, during an unusually heavy rain, measured the quantity which entered the gauge in ten minutes, and found that the fall had been at the rate of 5 inches an hour, or, in other words, that $\frac{5}{6}$ths of an inch had fallen in the ten minutes. According to Mr. Neville, it is stated that 4 inches of rain fell in one hour in the Holborn and Finsbury Sewers district.

For the sake of illustration, it will be assumed that a district exists in which the maximum rate of rainfall is 5 inches an hour, and the maximum value of the modulus M is 20. This requires that the origin of the co-ordinates be situated at a point in the parabola where its geometrical tangent is inclined to the axis of x at an angle whose trigonometrical tangent is 120. If x' and y' be the rectangular co-ordinates of the curve measured from this point, its equation is $y' = 20\sqrt{x' - \frac{y'}{120}}$; the areas being measured in square miles, and the discharges in cubic yards per second. But as, for small areas, it will be more convenient to measure the areas in acres, and the discharge in cubic feet per second, the formula becomes, when adapted to these new measurements,

$$y' = 21{\cdot}4\sqrt{x' - \frac{y'}{5}}$$

very nearly, or, after the solution of this quadratic equation,

$$y' = -45{\cdot}796 + \sqrt{2097{\cdot}28 + 457{\cdot}96\,x'}.$$

The following table shows the discharge in cubic feet per second, from districts increasing in size from 10 acres to 5 square miles, computed by this formula. It illustrates the rapid diminution in the rate of discharge per acre, and in the proportion of the rainfall represented by the rate of discharge as the area drained increases :—

Area of District.		Maximum Discharge in Cubic Feet per Second.	Maximum Discharge in Cubic Feet per Second per Acre Drained.	Representing Rainfall per Hour in Inches.
Square Miles.	Acres.			
	10	35·916	3·592	3·56
	50	112·303	2·808	2·78
	100	173·050	1·730	1·72
	200	260·291	1·301	1·29
	300	327·682	1·092	1·08
	400	384·647	·962	·95
	500	434·909	·870	·86
1	0	497·520	·777	·77
2	0	721·302	·564	·56
3	0	893·023	·465	·46
4	0	1037·934	·405	·40
5	0	1165·638	·364	·36

While the discharge from an area of 10 acres represents a rainfall of 3·56 inches an hour, that from a district having an area of 5 square miles represents a rainfall of only ·36 of an inch.

It is convenient to express the discharge in cubic yards per second, and the areas in square miles, for large districts, because a rainfall of 1 inch per diem is represented approximately by a discharge at the rate of a cubic yard per second per square mile drained. In the case of small districts the discharge is more conveniently expressed in cubic feet per second, because a rainfall of 1 inch per hour is represented approximately by a discharge of a cubic foot per second per acre drained. The error in the first case is rather less than $\frac{5}{12}$ths per cent.; in the second it is $\frac{10}{12}$ths per cent.

It will be seen, however, from the last table, that it is only in the case of very small districts that the rainfall in so short time as one hour is correctly represented by the drainage discharge. The rates of flood discharge from a series of districts increasing in size would represent the mean fall of rain for several hours, days, and weeks; the rates of flood discharge from the largest districts representing the mean rate at which the rain fell for the longest periods. In the case of the St. Lawrence it is even stated, that the moderating influence of the great lakes is such, that the discharge of the river scarcely varies from its annual mean. If this be true, the rate at which the St. Lawrence discharges cannot even represent the mean rate of rainfall per annum over its whole basin, for some loss of rain occurs from evaporation and absorption, and the remainder only finds its way by the river.

The following statement will show, however, that in rivers whose basins are by no means small, very extraordinary floods may occur in years not remarkable for large totals of rainfall; the floods being produced in a cool season of the year, in a comparatively short

time, by rain falling in quantities not large enough to raise the annual total above the average. The Seine, before passing Paris, has drained about 20,000 square miles of country. In a Paper in the "Annales des Ponts et Chaussées,"[1] it is stated that "in 1740, a year of formidable inundations throughout France, and, above all, at Paris, the annual mean fall of rain does not appear to have been much exceeded, but the first six months had been extraordinarily dry, and the two last extraordinarily rainy." In the year 1740 the Seine stood at 25 feet on the gauge at the Pont Royal of Paris, and it has never risen to the same height since. This fact also shows the uncertainty of great floods, and the consequent necessity of applying a factor of safety to the experience of the oldest inhabitant of a town situated near a river, if it be really important that the highest floods be provided for in an engineering work.

In India the memory of the oldest inhabitant is often the only possible, though frequently a very uncertain source of information, respecting the heights to which a river in any neighbourhood has risen.

The factor of safety to be adopted cannot be determined beforehand, because information on the subject is still very imperfect. The adoption of the same factor for all parts of the world, or even of the same country, would in many cases lead to extravagant expenditure of money. There must, however, be for each river a factor, which applied to the average of, say ten years, in which the rainfall is known to have exceeded the average of twenty-five successive years, would express without undue exaggeration the greatest probable flood of the next century. The examination of all existing records of river gauges and rainfall would probably throw much light on the subject generally, and furnish hints in dealing with districts for which no records exist.

In conclusion a few statements and quotations will be given, as affording examples of flood moderators.

The effect of lakes is so well known as scarcely to need a reference. To this may be attributed the low value of the modulus M for the River Po, as compared with the Danube; the value for the first being only 37·9, while for the second it is as high as 74 at Pesth, and 67·53 at its mouth. Both these rivers drain the Alps, and the proportion of mountains receiving heavy falls of rain to the whole area of the basin is, if anything, greater in the case of the Po than in that of the Danube. The mean fall of rain per annum, as given by Mr. Keith Johnston,[2] is 57·57 inches for the south face of the Alps, and only 35·27 inches for the north face; so that, if there were no lakes in the basin of the Po, its modulus would most probably have been more than double what it is at present.

[1] *Vide* 4e série; tome 10, p. 50.

[2] *Vide* "The Physical Atlas of Natural Phenomena," 2nd edition, p. 66.

The River Thames furnishes a striking example of floods being moderated by the geological structure of a drainage basin. A very large proportion of this basin consists of chalk. Mr. S. C. Homersham, M. Inst. C.E., has contrasted the waterway and the drainage grounds of nine pairs of bridges[1]—one bridge of each pair crossing a stream draining an area of chalk, and the other crossing a stream draining a nearly equal area of the London clay, or of London clay with a little chalk. The ratios of the waterways of the bridges crossing streams draining chalk to the waterways of the bridges crossing streams draining clay varies nearly from $\frac{1}{10}$th to $\frac{3}{10}$ths, and while the former were never full of water, and sometimes never two-thirds filled with water, the latter were often filled with flood water. The velocities of the streams are not given. It is not, therefore, possible to make the comparison accurately, but enough is stated to show the decided effect of chalk in moderating floods, and to account for the low value of (M) the modulus for the Thames, viz., 5·24.

The beds of most rivers of Southern India are dry for many months in the year. Some of these beds appear to be connected with extensive strata of sand near the sea, so that the first floods of the wet season are very much moderated, and in some instances lost before reaching the sea. The Pennair, a river entering the sea near the town of Cuddalore, has a total length of 250 miles. It drains about 6,000 square miles of country. The water was 3 feet deep in this river at Munnaloorpett on the 16th of May, and again 6 feet deep on the 4th of June, 1855, at Riandaveraw, while at Cuddalore there was no sign of a fresh, the whole having been absorbed in the 60 miles of river bed lying between the two last places mentioned.

The moderating influence of the channel of a main river upon floods delivered into it by its tributaries is exemplified on a magnificent scale in the river Mississippi, as the following extract from the Report on the Mississippi by Captain Humphreys and Lieutenant Abbot clearly shows:[2]

"The rise in December, 1857, admirably illustrates this influence, since the water was then entirely confined to the channel, and the effect of crevasses is thus eliminated from the problem. This rise was at its height (8·5 feet below high water of 1858) at Columbus on December 21, the maximum discharge being 1,190,000 cubic feet per second. The St. Francis river was backed up, and contributed nothing. At Napoleon, the rise attained its highest point (7·1 feet below high water of 1858) on December 28. On December 29, the measured discharge of Arkansas river was 65,000 cubic feet per second. On January 1, the river had fallen 2·2 feet at Napoleon, and the measured discharge of Arkansas river was 59,000, and of White river 48,000 cubic feet per second. It is evident, then, that these two rivers must have added at least 100,000 cubic feet per second to the top of the flood wave, as it

[1] *Vide* "The Civil Engineer and Architect's Journal," vol. xviii., p. 75.

[2] *Vide* "Report upon the Physics and Hydraulics of the Mississippi River;" &c., p. 349.

passed. At Yazoo river, according to accurate data, it received 45,000 cubic feet per second more. At the top of the flood at Natchez, which was 8·3 feet below high water, 1858, the discharge then should have been 1,190,000 + 100,000 + 45,000 = 1,335,000 cubic feet per second. It was measured on January 8, when the river had fallen 1·6 foot, and was found to be 845,000 cubic feet per second. Allowing a very liberal estimate for diminution of discharge at this date, the rise when highest could not have carried past Natchez more than 935,000 cubic feet per second. How, then, is this enormous difference of 400,000 cubic feet per second to be accounted for? Only in one way. The reservoir furnished by 550 square miles of channel between Columbus and Natchez absorbed it all. This is an extreme case, because such a rise at so low a stage is almost unprecedented, but it plainly shows that so important an element cannot be neglected in discussing the subject of river floods."

Sometimes one of the tributaries of a river, instead of increasing its flood, moderates it by receiving water at the height of the flood, and returning it to the main river when that is falling. M. Dupuit states[1] that the Maine relieved the Loire for three days when the flood of 1846 was at its height at the rate of 1,000 cubic mètres per second. So that the Loire below the mouth of the Maine was discharging 1,000 cubic mètres per second less than above the mouth of that river.

The Paper is illustrated by two Diagrams, from which Plates 9 and 10 have been compiled.

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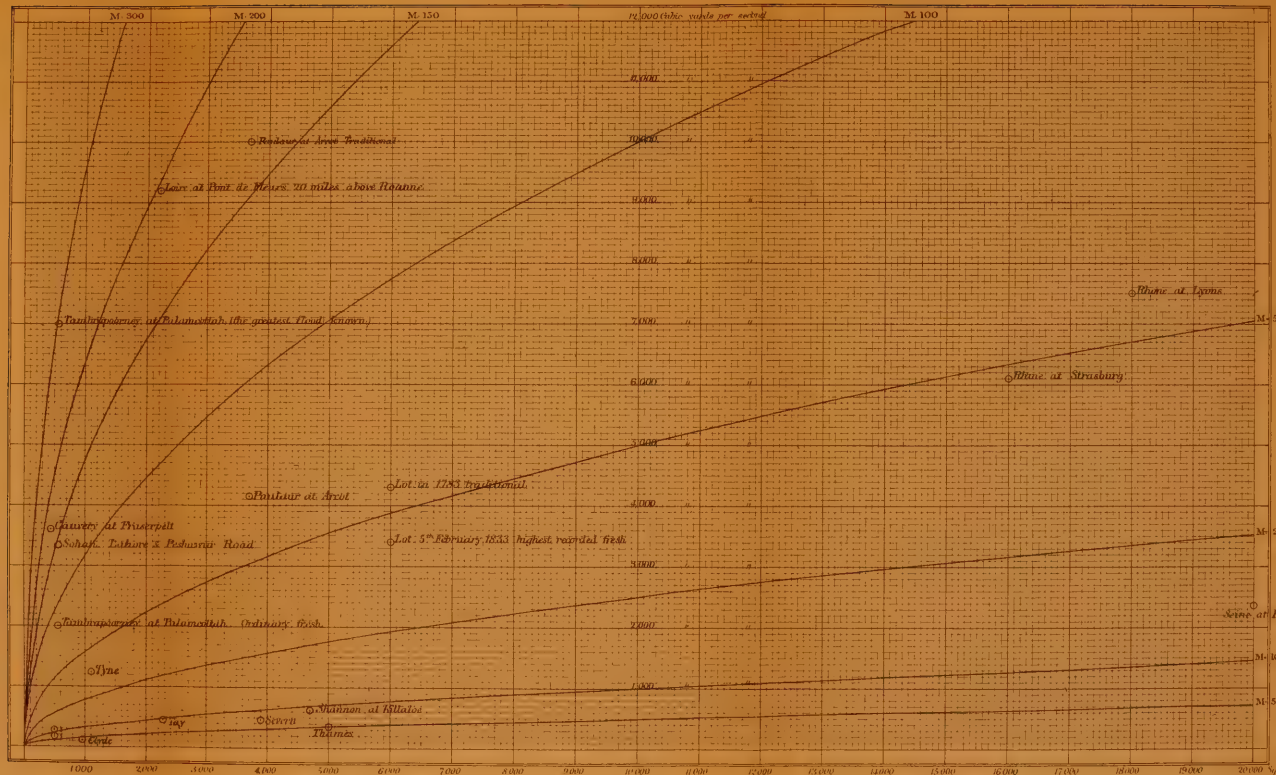
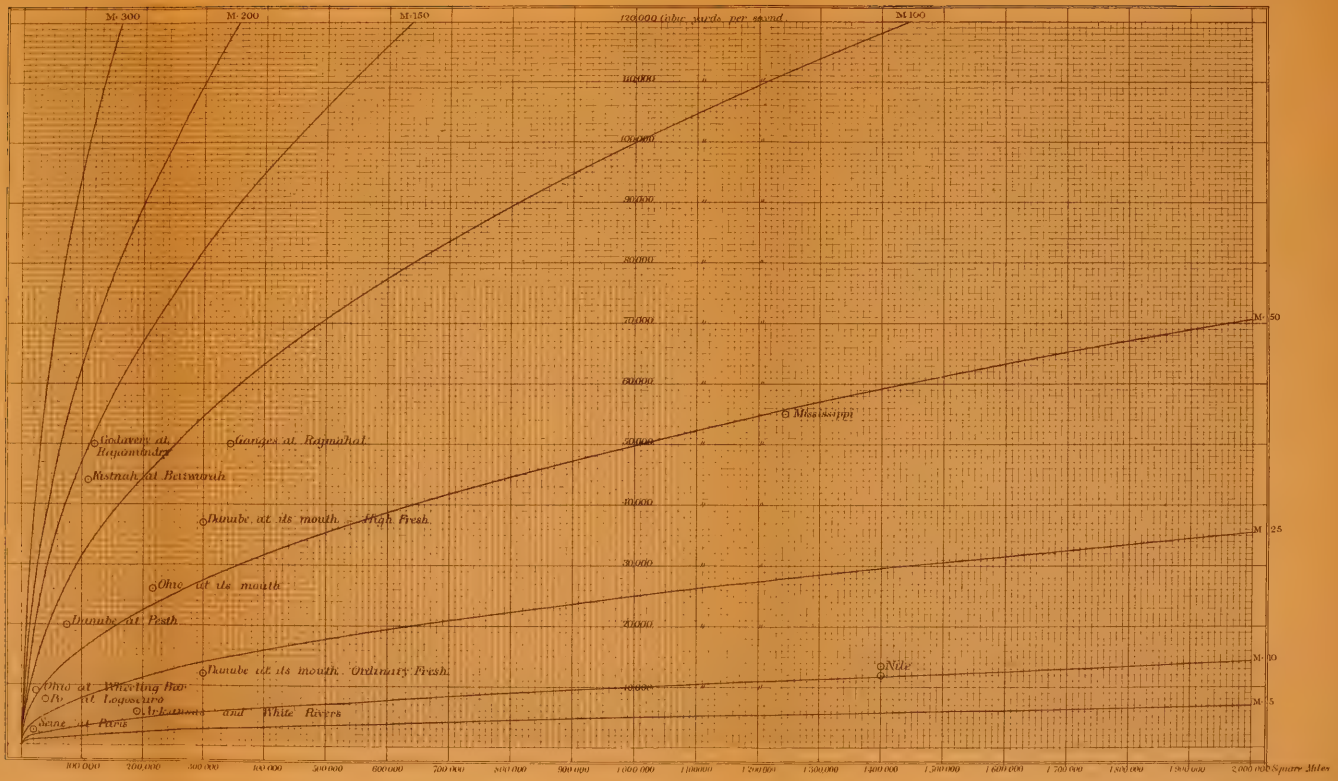
[1] *Vide* "Études théoriques et pratiques sur le Mouvement des Eaux," p. 163.

FLOOD DISCHARGE OF RIVERS.




M·300
M·200
M·150
M·100
M·50
M·25
M·10
M·5
130,000 Cubic yards per second
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
Mississippi
Godavery at Rajamundry
Ganges at Rajmahal
Nistnah at Betzwada
Danube at its mouth. High Fresh.
Ohio at its mouth
Danube at Pesth
Danube at its mouth. Ordinary Fresh.
Nile
Ohio at Wheeling Bar
Po at Loquerro
Arkansas and White Rivers
Seine at Paris
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000
1,200,000
1,300,000
1,400,000
1,500,000
1,600,000
1,700,000
1,800,000
1,900,000
2,000,000 Square Miles

APPENDIX.

Table Exhibiting a few of the Physical Features of Certain Rivers.

Continent and Country to which the River belongs.	Name of the River.	Area of its Basin in English Square Miles.	Flood Discharge of the River in Cubic Yards per Second.	Flood Discharge of the River in Cubic Yards per Second, per Square Mile Drained.	Values of M.	Authorities for the Statements recorded in Column 4, with some additional Information.
North America.						Mean Rainfall per annum. / Ratio between Drainage and Downfall.
United States	The Mississippi . . .	1,244,000	55,000	·044	49·28	30·4 / ·25 — Captain Humphreys and Lieut. Abbot's Report.
	Ohio at Wheeling Bar .	25,000	9,000	·36	57·	
	Ohio at its mouth . .	214,000	26,000	·122	56·	41·5 / ·24 — Captain Humphreys and Lieut. Abbot's Report.
	Red River	97,000	8,333	·086	26·76	39· / ·20 — Captain Humphreys and Lieut. Abbot's Report.
	Arkansas and White Rivers	189,000	5,930	·0313	13·06	29·3 / ·15 — Captain Humphreys and Lieut. Abbot's Report.
	Yazoo River	13,850	5,160	·372	44·1	46·3 / ·90 — Captain Humphreys and Lieut. Abbot's Report.
Europe.						
England . .	Thames	5,000	293	·0586	4·15	Encycl. Britannica. Article, 'Inland Navigation.'
			370	·074	5·24	Ditto ditto Ditto
	Severn	3,890	464	·119	7·4	Beardmore's Hydraulic Tables, page xxvii.
	Tyne	1,100	1,233	1·12	37·	Ditto ditto
	Nene at Higham Ferrars	383	79	·207	4·03	Ditto ditto
	Meadow Land . . .	·128	·1536	1·2	·43	Ditto ditto, page xxviii.
Scotland . .	Tay	2,283	465	·203	9·75	Encycl. Britannica. Article, 'Inland Navigation.'
	Clyde	945	120	·127	3·9	Ditto ditto Ditto
	Conon	399	133	·333	6·7	Ditto ditto Ditto
	Earn	340	132	·39	7·2	Ditto ditto Ditto
Ireland . .	Shannon at Killaloe . .	4,687·5	617	·132	9·01	Neville's Hydraulics, 2nd edition, page 298.
	Lower Erne at Belleek .	1,521·9	404	·265	10·04	Ditto ditto
	Upper Erne at Belturbet	482·8	159	·329	7·4	Ditto ditto
	Woodford at Ballyconnell	140·6	62·2	·442	5·24	Ditto ditto
	Yellow River	7·8	32·1	4·12	11·46	Ditto ditto
	River Robe at Ballinrobe	110	71	·645	6·8	Ditto ditto, page 302.

Table Exhibiting a few of the Physical Features of certain Rivers – *continued.*

Continent and Country to which the River belongs.	Name of the River.	Area of its Basin in English Square Miles.	Flood Discharge of the River in Cubic Yards per Second.	Flood Discharge of the River in Cubic Yards per Second, per Square Mile Drained.	Values of M.	Authorities for the Statements recorded in Column 4, with some additional Information.
Europe.						
France . .	Seine at Paris . . .	20,000	2,350	·116	16	Dupuit, 'Études Théoriques et Pratiques sur le mouvement des Eaux,' page 191.
	Rhone at Lyons . . .	18,000	7,500	·416	56	D'Aubuisson's Hydraulics. English Translation by Bennett, page 174.
	Rhine at Strasbourg . .	16,000	6,100	·381	48	Ditto ditto ditto.
	Loire at Pont de Fleurs, 20 miles above Roanne	2,200	9,200	4·18	196	Flood of October, 1846. *Vide* Beardmore's Hydrology, page 161.
	Lot, a tributary of the Garonne	6,000	2,770	·461	35·7	7th January, 1860
			2,783	·464	35·85	1st June, 1856
			2,790	·465	36	26th January, 1856
			3,400	·566	43·9	5th February, 1833
			4,320	·720	55·3	1783; tradition.
						Annales des Ponts et Chaussées. Mars et Avril, 1865, page 154.
Italy . . .	Po at Ponte logoscuro .	40,000	7,580	·1895	37·9	Buffon, 'Traité des Irrigations,' vol. ii., page 31.
			6,760	·169	33·8	Courtois, 'Traité des Moteurs,' page 316.
	Reno	417	435	1·04	21·32	Buffon, 'Traité des Irrigations,' vol. ii., page 31.
Central Europe	Danube at its mouth .	300,000	12,000	·04	22·	Ordinary fresh
			37,000	·1234	67·53	High fresh
						Sir Charles Hartley. *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., pp. 278 and 281.
	Danube at Pesth . . .	72,850	20,000	·272	74·	High fresh. Rough and uncertain computation from data in the Supplement to the work on Bridges, published by Weale.
Africa.	Nile	1,400,000?	13,400	·00957	11·38	Encyclopædia Britannica, vol. xvii., page 608.
			12,000	·00857	10·17	Captain Fyfe, R.E., in a Report to the Bombay Government.

Table Exhibiting a few of the Physical Features of certain Rivers—*continued.*

Continent and Country to which the River belongs.	Name of the River.	Area of its Basin in English Square Miles.	Flood Discharge of the River in Cubic Yards per Second.	Flood Discharge of the River in Cubic Yards per Second, per Square Mile Drained.	Values of M.	Authorities for the Statements recorded in Column 4, with some additional Information.
Asia.						
India . . .	Ganges at Rajmahal .	345,000	50,000	·145	85	Major Lang, Superintendent of the Nuddea River, in No. XIX. of the 'Selections from the Records of the Government of Bengal.'
	Godavery at Rajahmundry	120,000	50,000	·416	144·3	
	Kistnah at Beizwarah .	110,000	44,000	·4	133	
	Toombuddra at Kurnool	20,000	10,000	·5	70·2	Captain (now Colonel) Lawford, R.E.
			22,000	1·1	155·5	Captain Beckley, R.E. Probably too high an estimate.
	Cauvery at Seringham .	28,000	17,500	·625	104·	
	Ditto at Fraserpett . .	415	3,600	8·7	177·	
	Pennair at Nellore . .	20,000	13,300	·67	94·4	
	Palaur at Arcot . . .	3,700	4,160	1·12	68·8	Colonel Collyer, R.E.
			10,000	2·7	164·39	Tradition.
	Tambrapoorny at Palamcottah	587	2,000	3·4	82·37	Ordinary fresh.
			7,000	12·	289·	Inundation, described in the Government Records of the Tinnevelly district.
	Chittaur at Alligiyapandiyapooram . . .	486	200	·41	9·07	Ordinary fresh.
			1,100	2·26	49·9	Extraordinary fresh.
	Vigay at Madura . .	1,600	800	·5	20·	Ordinary fresh.
			1,600	1·	40·	Extraordinary fresh.
	Munjelnaltree at Ballagoontoo	90	400	4·44	42·16	Ditto ditto.
	Varhaganaltree at Periacolum	41	300	7·3	46·8	Ditto ditto.
	Irrity in Malabar . .	336	3,700	11·	201·8	General Ludlow, R.E.
			5,550	16·5	302·7	
	Sohan River, Lahore and Peshawur Road . .	573	3,370	5·9	141·	'Indian Engineering,' vol. i., page 177.

February 4, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—John Wolfe Barry, James Craig, Charles Henry Denham, and David Reid Edgeworth, as Members; Fritz Bernard Behr, Richard Broome, William Henry Cock, Frederick Charles Danvers, Edwin William de Rusett, Charles William Dixon, William Frederick Faviell, Alfred Francis John Fisher, John Henry Greener, John Tunstall Haverfield, Captain, Royal Marines Light Infantry, William Robert Johnson, Captain, Madras Staff Corps, James Ouchterlony Macdonald, Thomas Boustead Nelson, Lionel Henry Shirley, Arthur Telford Simpson, Henry Edward Thornton, and Thomas Walker, as Associates.

It was announced that the following Candidates having been duly recommended, had been admitted by the Council, under the provisions of Sec. IV. of the Bye-Laws, as Students of the Institution:—John Hopwood Blake, Joseph Cash, Raymond Edmiston, Malcolm Graham, Charles Edward Jones, James Verchild Ley, Morton Kelsall Peto, William Herbert Peto, Charles Edward Robinson, Arthur Toulmin Smith, Edward Herbert Stone, and Frank Napier Thorowgood.

No. 1,186.—"Floods in the Nerbudda Valley: with remarks on Monsoon Floods in India generally."[1] By Andrew Cassels Howden, Assoc. Inst. C.E.

One of the chief wants experienced by the Civil Engineer in India arises from the scantiness of information regarding the periodical monsoon floods, to which the rivers especially and the country generally is subject. Much valuable information probably exists in the hands of the Engineers now engaged upon the numerous public works throughout the country, but, as it has never been collected for reference in any tangible form, it is for all practical purposes comparatively useless.

The observations contained in this Paper are necessarily incomplete; the limited extent of the district under review, and the difficulties inherent in a new, and to some extent unknown country, render this unavoidable. But if the Author succeeds in eliciting

[1] The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

the views of others, who may have had better opportunities of observation, a service will have been rendered to Indian engineering.

The Nerbudda Valley is bounded on the north by the Vyndhya Mountains, and on the south by the Sautpoora range. (Plate 11, Fig. 2.) It consists principally of what is known as black cotton soil, and is renowned for its fertility. The immediate drainage of the valley supplies nearly the whole volume of the waters of the Nerbudda River, which traverses it in a direction nearly due east and west. The total length of the river is 800 miles; it takes its rise from a pond on the elevated plateau of Amarkantak, in the Vyndhya Mountains, at an elevation of 3,500 feet above the sea; its fall to Jubbulpore, 190 miles distant, is 10 feet per mile, and from this point to the Gulf of Cambay the fall may be estimated at about 2 feet per mile.

The width of the river at its source is a yard, while a little above its confluence with the Towah, 360 miles down stream, it is 900 yards, and at its mouth it exceeds a mile. The river rises between 30 and 40 feet in an ordinary monsoon, but it has been known to rise nearly 60 feet and to overflow its banks.

Perhaps few rivers of similar magnitude and length receive so few tributaries. The principal of these are, the Herrun, the Shair, the Towah, the Gunjal, and the Suktha or Chota Towah.

Midway between the river and the Sautpoora Mountains, the valley for a length of about 270 miles is traversed by the north-eastern extension of the Great Indian Peninsula Railway, which thus crosses all the tributaries that fall into the river on its southern bank, and it is the floods to which these feeders are liable, rather than the Nerbudda River itself, that will form the subject of the present Paper.

The floods of this region may be divided into two classes, viz.:

1st. Those affecting the plains.

2nd. Those affecting the rivers.

1st. The floods affecting the plains:—

The average rainfall in the valley for the last fifteen years has been 45·97 inches per annum distributed over the four monsoon months, from June to September; but the maximum amounted to 64·05 inches, while the minimum was 30·5 inches. Taking the average of the mean fall, it would give about 11·5 inches per month, a quantity which the natural watercourses are sufficient to provide for; but as 10·50 inches have been known to fall during eighteen hours (as was the case in August, 1864), these have been found inadequate, and the result has been sudden and disastrous floods.

TABLE of RAINFALL in the NERBUDDA VALLEY.

Year.	Inches.	Locality.	Year.	Inches.	Locality.
1852	49·35	Hoosungabad.	1860	40·10	Hoosungabad.
1853	48·20	Ditto.	1861	50·45	Ditto.
1854	35·30	Ditto.	1862	52·20	Ditto.
1855	31·75	Ditto.	1863	52 19	Rampoor.
1856	63·35	Ditto.	1864	43·39	Hurda.
1857	64·05	Ditto.	1865	41·20	Ditto.
1858	48·45	Ditto.	1866	39·06	Ditto.
1859	30·50	Ditto.			

The first eleven years were kept by Surgeon Trimnell, of the 1st Regiment M. N. I., at Hoosungabad; the last four years by Messrs. Hood, Winton, and Mill, Contractors. Contract 16, G. I. P. Railway.

The greater part of the Nerbudda Valley traversed by the railway is almost a level plain, with only a slight fall towards the rivers, and intersected with few natural watercourses. This being the case, the railway embankments form an artificial bund or dam right across the country, intercepting the natural flow of surface water, and causing floods, which without this obstruction would not exist. This tendency seems to have been underrated, when the gradients were first laid out, and probably a too great leaning to economy may have contributed to the same result; but wherever this has occurred, the rail level has had to be considerably raised, and additional waterway provided.

Floods of this description took place near the town of Hurda in 1864 (said by the natives to be the highest known for thirty years), washing away completely several miles of shallow embankment, and even tearing large holes in the seat, and leaving the permanent way twisted upon the cess. This portion of the line was raised 6 feet, and double 30-feet girder bridges built where 2-feet culverts formerly existed.

Near the village of Tamurnee also, in 1864-5, the embankments were cut through in several places, and much damage done, necessitating the raising of the gradients for upwards of 5 miles, and the provision of a large amount of additional waterway. For the whole of this distance there was not a single well-defined watercourse. Other districts of the Great Indian Peninsula Railway have also suffered, more especially portions of Contract No. 17, and in the Concan. In 1866 about 75 miles of the Scinde Railway, and 30 miles of the Bombay, Baroda, and Central India Railway were for all practical purposes rendered useless. The East Indian Railway also suffered considerably. A full discussion of the causes and means of prevention of these and similar disasters is of the utmost importance. The lessons to be learned are many and obvious.

In carrying a railway across plains of the description referred to, great attention must be paid to the rainfall of the district, and ample provision must be made for carrying off the maximum amount speedily, without causing it to dam up, as few embankments (especially those formed of black soil) can withstand the immense pressure then brought upon them, although the period of danger may not exceed twelve hours during the year; and should an opening once be formed, the scour is such that the embankment speedily melts away. Black soil embankments, from the dry state of the material when put together, will frequently shrink to the extent of from 25 to 40 per cent. They are also subject to extensive cracks and fissures in the dry season. Great care should therefore be taken in closing in behind the abutments of bridges as the work proceeds, thus ensuring the earth being well trodden down, instead of, as is frequently the case, being filled in afterwards with loose and dry material. Those portions subject to backwater and scour should be protected by retaining walls and pitching. Embankments of this description, however, are of so treacherous a nature that, even after every precaution, the water will frequently force its way through, and leave the bridge isolated. The Chief Engineer of the Bombay, Baroda, and Central India Railway, mentions in one of his reports a case in which a black soil embankment adjoining the Keem Bridge on that railway was pushed bodily over 18 inches, bending the permanent way to that extent. A case also occurred with a shingle embankment on the Great Indian Peninsula Railway, near Bhosawul, at the Sookee Nuddee, the waters of which rose during the night of the 26th of June, 1867, and washed away a length of 50 feet of bank behind the abutment, when, unfortunately, several lives were lost.

An Engineer new to India, and with only European experience, would be surprised to see in many cases bridges in an open plain, with neither road, river, nor water for miles. Should he, however, revisit the spot during a monsoon flood, the cause would be apparent: he would then see the dry plain transformed into a lake, and the water rushing through the openings with the force and rapidity of a mill-race.

The second class of floods are those affecting the rivers.

The principal rivers crossed by the Great Indian Peninsula Railway, in the portion of the Nerbudda Valley to which this Paper refers, from Bhere to Bagra—a distance of 100 miles, are, the Towah, Gunjal, Matchock, Karlee Matchock, and Suktha or Chota Towah rivers, besides the Sconce Jamnee, Hurda, and other nullahs.

The greatest flood known for the last ten to fourteen years (the natives say thirty) occurred in 1864, and gave a favourable oppor-

tunity of watching its effect upon the rivers and nullahs before mentioned.

The largest and most important river is the Towah, which rises in the Sautpoora Mountains, and receives the watershed of between 500 and 600 square miles of country. Neempani, near one of its branches, is shown upon the only trigonometrical map extant as 2,700 feet above the sea, and Bagra, where the viaduct crosses, as 1,150 feet, giving a fall of 1,550 feet, in a distance of 50 miles, equal to the extraordinary fall of 30 feet per mile. This will account for the unusual features that occur during its floods. Beyond this, the fall (from calculation) is about 4·25 feet per mile. This will not, however, give the true velocity, as the immense impetus the water receives before reaching the plains must materially increase it. It will be seen from the Table (p. 224), that the calculated velocities for the Gunjal River fall short of the actual ones.

The Towah Viaduct, as originally designed, consisted of eleven spans of 74 feet each, with the rail level at a height of 74 feet above low water; but when the piers were partially built, an immense flood occurred, on the 15th of August, 1864, and the river rose 47 feet in a few hours and washed away piers 6 and 7, the former being 85 feet and the latter 39 feet in height. The aspect of the flood on this occasion presented several interesting features, and the Author is greatly indebted to Mr. C. J. Shaw, the Engineer in charge, for much valuable information regarding it.

No correct gauge was kept of the rain that fell, but in the great floods on the same occasion at Hurda 10·50 inches were gauged in eighteen hours, and it may be assumed that an equal quantity fell here. It appears that the level of the water at the west bank, or abutment No. 1, was 90·00; on the east bank, or abutment No. 2, it was 97·25, while at piers 6 and 7, it was 101·00; the cross section of the stream thus forming a curve (Plate 11, fig. 1); the obstruction caused by the piers damming back the river to this extent. No observations as to the velocity of the current were taken, but assuming it to have been the same as at the Gunjal River during the great flood of the same year, viz., 16·58 feet per second at the surface, then the fall per mile must have been about 4·25 feet, and the discharge 976,629 cubic feet per minute.

In the succeeding monsoon of 1865 several observations were taken by Mr. C. J. Shaw. Rain fell from the 16th to the 19th of July. The level of the river on the morning of the 19th was 86·00, and in the afternoon, at abutment No. 1, 90·00, the same as in the previous year. There was little backing up at 86·00, but it became alarming at an increased height of 4 feet, viz., when the river stood at 90 00. The side elevations of piers 8 and 9 (Plate 11, figs. 7 and 8,) show the action of the water. It will be seen that at the former there was a fall of 10 feet, and at the

latter 7·50 feet, from the cutwater to the back of the pier; whirlpools were formed at the down-stream end, and waves of from 6 feet to 10 feet in height both above and below the viaduct. On the morning of the 20th the river had fallen 12 feet and was tranquil, with no backing up.

The original piers of the Towah Viaduct were of nearly similar dimensions to those at the Gunjal, 12 feet wide to the first plinth, 11 feet to the second, and 10 feet above. After the disasters of 1864 Mr. R. W. Graham (M. Inst. C.E.), the then chief resident Engineer, resolved to convert the five centre spans into three, and to give an additional thickness to the four central piers of 3 feet 6 inches, carrying them up 13 feet 6 inches in width to the cutwater cap. Little was done during the season of 1864-65, when further observations on the floods were made. It was, however, determined by Mr. J. R. Rushton (M. Inst. C.E.), who succeeded Mr. Graham, to convert the three centre openings into two spans of 202 feet 6 inches each, with a massive elliptical central pier, built of solid block-in-course up to low-water level, and above that of the same description of work as the other piers, block-in-course face-work with rubble backing.

The flood of 1864 was affirmed by the natives to be a most unusual one; but that of 1865 was of similar dimensions, and the flood of 1866 exceeded its predecessors both in force and magnitude, showing, that if floods of this description did not occur annually, at least they happened far more frequently than was desirable.

The central, or No. 4 pier, as before stated, was built of solid block-in-course up to low-water level, and above that with block-in-course face-work with rubble backing, and during the working season of 1865-66 the masonry was carried up to the cutwater cap bed. During the flood of August the 9th, 1866, the level of the water at abutment 1, was 93·75, and at abutment 2, 105·75. The top of the masonry of pier 4, on the east side, was not visible; but on the lower, or west, it was. The fall of water from the cutwater to the back of the pier was 15 feet.

The pier was unable long to withstand the force brought to bear upon it, and was speedily carried away to a depth of 3 feet below the top of the solid block-in-course foundation. Pier 5 (corresponding to pier 8 in the first design) went at the same time, and being only 13 feet 6 inches in width, and built of block-in-course face-work with rubble backing only, it broke off at a level 6 feet lower. Some idea of the force of the current may be formed from the mass of masonry washed away, viz.:—

From Pier No. 4, about 1,600 tons in weight;
„ Pier No. 5, about 1,000 tons in weight;

and of this mass of materials not a stone was ever recovered.

The question then presents itself, What are the greatest floods to be apprehended, and also what influence would the height of water in the Nerbudda River have? On the present occasion the level of the Nerbudda was about 20 feet lower than it has been known to be; would a simultaneous high flood in the latter cause a dangerous backing up? or would the fact of the Nerbudda being low, and thus causing an increased fall of from 6 to 8 feet per mile, increase the velocity of the Towah in a dangerous degree?

It has been found that the remaining piers and abutments were so shaken as to render it advisable to remove the whole and reconsider the design; and it has now been decided that the viaduct shall consist of three central spans, of 202 feet each, flanked on each side by one of 132 feet, and the rail level to be raised 6 feet.

The piers are to be elliptical, to be built of solid block-in-course throughout, set in cement; the face-stones not to be less than 4 feet in length, 18 inches deep, and 2 feet on the bed, with cement dowells, and tool-dressed on the face.

The next important river is the Gunjal, or more properly the Moorum, the two streams forming a junction about half a mile above the viaduct, and 14 miles from the confluence with the Nerbudda. The Moorum branch is nearly 70 miles in length, while the Gunjal is only 50 miles, and of much less volume: both rise in the Sautpoora Mountains. The fall from the mountains must be very considerable, somewhat similar to that of the Towah; the fall at the viaduct itself has been found, from actual levels, to be 3 feet per mile. The highest known flood occurred in July, 1864, when the river rose 46 feet above low water.

Observations were taken during two subsequent floods in the year 1866. and from the data then obtained, the velocity and discharge of the former has been calculated.

TABLE showing the VELOCITY and DISCHARGE of the GUNJAL and TOWAH RIVERS.

Name of River.	Date of Flood.	Height above Datum.	Fall per Mile.	Area.	Wetted Perimeter.	Hydraulic Mean Depth in Inches.	Mean Velocity in Inches per Second.		Discharge in Cubic Feet per Minute.
							From Observation.	From Calculation.	
		Feet.	Feet.						
Gunjal	Aug. 29, 1866	73·00	3·00	4,968	345	172·80	110·22	99·57	109,494
Ditto .	Aug. 8, 1866	95·00	3·00	15,549	500	373·08	153·68	147·00	477,820
Ditto .	July 22, 1864	103·84	3·00	22,032	557	474·60	..	166·14	732,123
Towah.	Aug. 15, 1864	101·25	4·25	29,390	1,108	318·24	..	166·14	976,629

Plate 11, Fig. 1, shows a plan of the river in the dry season; while Fig. 6 indicates the extent of backing up when the river stood at 95·00. No observations, as before stated, were taken when the river was at its highest, viz., 103·84; but it may be conjectured as having been much greater, the backing up increasing rapidly with every foot of rise in the river. The depth of water in the dry season ranges from a few inches to as many feet. The viaduct consists of eight spans of 85 feet from centre to centre (Fig. 4), and the rail-level is at 61·00 feet above low water. The piers are built of block-in-course face-work with rubble backing, with through plinth courses of solid block-in-course. The stone employed was sandstone of a superior quality. No difficulty was experienced in founding any, with the exception of No. 2 abutment, and all are on rock. Work was commenced in 1862, and the girders were fixed by the commencement of the monsoon of 1866, and the whole was completed and ready for inspection early in 1867.

Some idea of the force of the current in Indian rivers may be formed from the fact that when the Mulkapoor Viaduct, on the Nagpore extension, was washed away in 1864, some of the 30-feet plate-girders were carried 7 miles down stream, and this in comparatively a small river.

After the rivers, the effect of floods on the smaller streams, or nullahs, falls into insignificance, but, as this Paper has grown to larger proportions than was intended, mention of them has been omitted.

No absolute rule for the avoidance of accidents of this description can be given, nor will any attempt be made to do so on the present occasion; but a few of the more obvious precautions may be noticed.

First, wide spans are indispensable. The current in Indian rivers is so swift, and the rise of water so rapid, after a heavy fall of rain, that any contraction of the waterway causes a dangerous scour and backing up. In the nullahs referred to, crossed by 30-feet girders, about $\frac{1}{6}$th of the waterway is occupied by the piers, and at the Gunjal, and the first design for the Towah, about $\frac{1}{10}$th.

Secondly. Next in importance to having as few piers as possible, is the necessity of giving them the greatest strength by building them of solid block-in-course, set in cement. The chunam or lime of India, to ensure setting, requires to be freely watered and exposed to the air, necessitating the work being carried on slowly. In large works this is impossible. The mortar in the centre of the structure would require years to harden, and in its soft state it is quite unable to withstand the pressure that may be brought to bear upon it, probably during the first monsoon, and which, although it may not destroy, will so shake the work as to lead to its ultimate

destruction. In positions and under circumstances where perfect setting may be relied on, it would be quite able to withstand any force that might be brought to bear upon it.

An instance of the non-setting properties of this lime occurred near Hurda, where an abutment of the viaduct was removed to increase the waterway. The mortar in the top and outside courses was completely set, in fact nothing could be better. The greatest difficulty was experienced in demolishing the work with crowbars, &c., and in many instances the stones were fractured before the mortar gave way, whereas in the centre it was found in a plastic state. This masonry was upwards of three years old, and the lime used of the best description.

Thirdly. The face of the cutwaters of piers should always be tool-dressed to reduce the friction, the 'bush' frequently left on forming a great obstruction.

Fourthly. In cases where rubble-backing is used, care should be taken in suspending work to finish off below high-water level with a through bed of solid block-in-course, otherwise the water will penetrate the work, and speedily blow up the pier.

In discussing these failures great allowance should be made for the trammels with which the Civil Engineer in India is encumbered, and the limited means at his command. In the first place, economy compels the use of such materials as are found on the spot, and his skill is required to turn them to the best advantage. Unfortunately, the stone may be inferior and the lime worse, and unable to withstand the test of age and exposure.

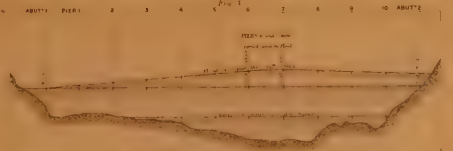
The difficulties of transport form another impediment. The impossibility of conveying ironwork beyond a certain weight and bulk necessitates the adoption of smaller spans than would be otherwise advisable, while at the same time the structures are put to the severest test. If, therefore, failures occasionally happen, it is not to be wondered at, but rather that they are not of more frequent occurrence. As, however, civilization and improved means of transport increase, and the vicissitudes of the climate are better understood, failures will cease to be more frequent than in more favoured countries.

The Paper is illustrated by a series of drawings, from which Plate 11 has been compiled.

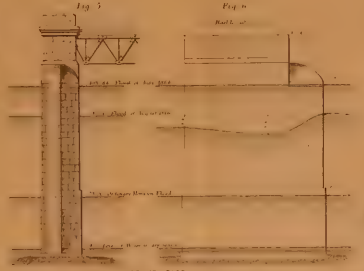
NERBUDDA VALLEY VIADUCTS.

PLAN OF GUNJAL RIVER

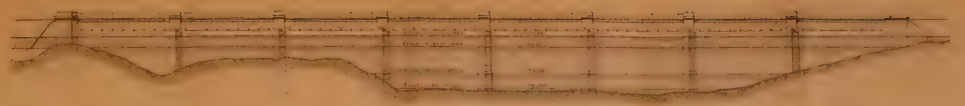
MAP OF PORTION OF NERBUDDA VALLEY



SECTION OF TOWAH RIVER



GUNJAL VIADUCT PIER
END ELEVATION — SIDE ELEVATION



GUNJAL VIADUCT ELEVATION

TOWAH VIADUCT
SIDE ELEVATION OF PIERS 8 & 9 DURING FLOODS OF AUGUST 1865

PLAN
TOWAH VIADUCT CENTRAL PIER

APPENDIX.

Containing Extracts from various sources.

Floods on the Scinde Railway.

"Mr. John Brunton, M. Inst. C.E., in his pamphlet on the Scinde Railway, states the average rainfall—we believe throughout the whole length of the line to Kotree—for the five years, 1856-60, as 4·82 inches."—*Times of India*, Sept. 17, 1866.

Rainfall between Kurrachee and Kotree.

"Measured by Scinde Railway Officials, from August 4th to 17th, 1866, or fourteen days, was as follows;—

	Inches.		Inches.
Kurrachee	10·10	Joongshaie	41·49
Landi	16·00	Hillgate	25·41
Guggur	32·00	Mayting	19·36
Dorbajee	40·24	Bolari	14·35
36½ miles, and at Kharaseer .	40·60	Kotree	11·57

"The rainfall of 1866 in Scinde, as also in Kattywar, will long be spoken of by the people of those provinces as a time to be remembered with dread. It is chronicled by whole villages overturned, fertile land devastated, roads rendered impassable, &c. The Mooktyear of Kurrachee has sent in a report of the destruction that has been ascertained, apparently from the flooding of the Mulleer alone." . . . "Ninety human lives have been lost; 4,359 grazing stock, and 158 draught animals have been swept away." . . . "The Mulleer Viaduct washed away is 12 miles from Kurrachee; the Bahrum about the same distance this side of Kotree." . . . "The first breach is between Kurrachee and Landi, 9½ miles from the former, and is 70 yards in width. At 12¼ miles from Kurrachee is Bolton Road crossing; and from this road down to the Mulleer River, about a mile, the line has been almost destroyed; two culverts only remain, with the bank immediately over and adjoining them." . . . "At one place in this length the flood was strong enough to break the fish plates, and several rails have been carried 50 yards. The most important works that have suffered are the Mulleer Viaduct, the Joonshaie Bridge, and the Joolajee Bridge. Each of these will require six weeks to be repaired, provided no further rain occurs."—*Scindian*, Aug., 1866.

The following is extracted from the Report made by Mr. McNeill, acting agent of the Scinde Railway:—

"The Mulleer Viaduct was 1,800 feet long, in twenty-one spans of 80 feet each, built on stone piers, each pier consisting of two upright pillars, sufficient only for a single line. The foundations were of three kinds. Piers 1, 2, 5, 6, 7, and 8, built in brick wells; 3 and 4 in coffer-dams; the remainder had piles driven in the wells, and filled in with concrete. Two rivers meet the Mulleer above the viaduct, the Dumb about half a mile above, and the Sookhan quite close to the bridge. The sources of these streams are widely separated, and it would appear on the morning of the 5th, when the viaduct was carried away, that the streams were discharging themselves at different levels, causing great turbulence in the water passing under the viaduct."

"At daybreak on the morning of the 5th there was little or no water visible in the bed of the river, and at 8 A.M. it had almost reached rail level. At 9 A.M. the bridge was carried away. The water came down in a succession of bores, the largest of which, bringing down with it the ruins of a village about a mile and a half up the river, came down with immense force, rising above the level of the rails, and carrying away eleven spans of girders, with their piers, as if they had been straws. Some of the girders are within a few feet of the bridge, but two of them are at least half a mile down the stream; each span, with rails, &c., would weigh about 60 tons."

"The abutment at the Kurrachee side stood well."

"Mr. Newnham proposes to carry up the piers 6 feet higher than they are now, filling them up solid; and where the foundations are made, as in piers 3 and 4, for a double line, to build them up their full width, also solid." . . . "The Joolajee Bridge carried away consisted of nine openings, 20 feet each, semicircular; bed of river to crown of arch, 20 feet. The water rose within 3 feet of the level of the rails or crown of arch."

"The Joongshaie Bridge consisted of six openings of 40 feet span each, semicircular arches. One pier has given way, and the bridge must come down, and the waterway be considerably increased. The water rose to crown of arches."

"I may say 60 miles of the line are useless for regular traffic until the diversions (temporary) are completed.

(Signed) "DAVID MCNEILL,
"*Acting Agent.*"

(From *Scindian*, Sept. 26th, 1866).

FLOODS, JUMNA RIVER.

(By Mr. G. Sibley, M. Inst. C.E., Chief Engineer East India Railway, N. W. P.)

"Lowest flood rises 30 feet above low-water mark.

Average ,, 40 ,, ,, ,, ,,
Maximum ,, 50 ,, ,, ,, ,,

"The year 1861 was remarkable not merely for the exceptional height, but also for the long duration of the floods—the river ran for eight days over 155·00, and for 4 days over 160·00. The maximum rate measured was rather more than 8 miles an hour, or about 12 feet per second (actually 950 feet in 81 seconds); for twelve days it ran over 10 feet per second.

"At the period of greatest discharge the mean surface velocity must have been 10 feet per second, and mean velocity of the whole stream upwards of 9 feet per second. The sectional area at that level being about 145,000 feet, it follows that the discharge per second must have reached the enormous amount of nearly 1¼ million cubic feet."

RAINFALL IN GUJERAT.

"Average rainfall in Gujerat 25 inches, discharge of Taptee at the end of the month of February, amounts to 100,000 cubic yards per hour."—*Gujerat Metra*, March 17th, 1867.

Mr. Gregory, President, said, he was sure all would agree that these Papers were not only valuable in themselves, but that they contained much that was suggestive to the engineer, and which would doubtless raise an interesting discussion. He could not help thinking, however, that some of the elements of calculation were of so variable and uncertain a character that it would be difficult to accept any formula of the nature proposed by Colonel O'Connell, as of universal application.

The Rev. J. C. Clutterbuck said, what he knew on the subject of the Paper was confined to a narrow area—the Thames Basin—though he had studied that area for many years. He did not believe there was any formula which could be fitted to rivers in general; there were so many causes whence floods originated, and so many by which they were modified. These must be clearly understood and separately treated. It was apparent that water which fell upon chalk was readily absorbed; and it was a happy thing, at any rate, for this part of England that there was a chalk stratum, otherwise there could not have been a London of its present magnitude. If the waters of the River Thames had been due to a water-shed which threw the water from its surface, there might have been a torrent, but it would have lacked those perennial waters, which, for the most part, issued from the chalk stratum, and formed the magnificent river running through the metropolis. But the question was one of floods, and not of water from the chalk. It must, however, be obvious that when perennial water was in excess, a flood would be more readily produced, and that which affected the perennial supply would tell on floods, in proportion as the flood waters met with a full or an empty river. Summer floods were an exception; as a rule, the water evaporated from retentive soils had to be replaced before any water could be thrown from their surface. His observations of many seasons showed that it required from $2\frac{1}{2}$ to 3 inches of continuous rainfall to replace in the autumn the water evaporated during the summer. When the soil was fully saturated, and not till then, could there be a flood. When snow fell on the frozen surface of the soil, and was succeeded by a sudden thaw, the greatest, most sudden, and most disastrous floods were produced. The highest floods on record, especially that in the year 1809, were due to this cause: indeed, for one hundred and thirty years all the greater floods of the River Thames had been caused by the melting of snows; a circumstance to which no formula would apply. Averages of rainfall could not be taken; it was the absolute rainfall within a given period, and a known area, and the geological and physical condition of that area, that must form the basis of every calculation. Even when all these points were considered, it would be difficult

to devise any formula which the complication of causes would not cast aside.

He would not enter at length on the subject of the upper district of the River Thames, because a few years back he had presented a Paper to the Institution on the perennial and flood waters of the upper Thames;[1] and he still adhered to the statements made in that Paper, as to the quantity of water brought down by the different rivers, the character of the tributaries, and the nature of their various water-sheds. The whole of the engineering of the River Thames was now under the supervision of a gentleman of undoubted ability and industry, whose whole heart was in it; and he was sure that a body of information exceedingly valuable, and of a practical character, was being acquired.

Professor ANSTED remarked that the subject required to be considered carefully, with reference to the points to which Colonel O'Connell had alluded, as well as those to which he had not paid so much attention. He thought also it would seem to those who were in the habit of looking at the question of the quantity of water that flowed off the surface of the earth, by rivers of different countries, at different seasons of the year, and under different circumstances, that a tabulated statement was wanted to compare one river with another in different parts of the world. That seemed to be one of the points of great value in the first Paper. It suggested a method comparatively simple, having in it certain elements of mathematical precision, and many indications of accuracy, which he thought would be found useful, and would enable those who wrote or thought on this subject, to bring together their ideas in better form than they had been in the habit of doing. He was not aware that this method of comparing rivers had been previously adopted, and he believed the suggestion to be of great value.

He thought there could be no doubt that rivers might fairly be divided into two classes, those that were greatly affected by floods, and those that were not; and it was certain that not only were there these flood-regulators, but that they were very numerous, and included others besides those to which Colonel O'Connell had alluded. Lakes were no doubt the most important regulators of all; but, as had been pointed out, the mere extension of the drainage area must act to a certain extent in the same direction; but the relative level to which a river rose, and the relative fall of a stream from the highest point down to the sea, was another important element in this matter. In countries where the mountains were lofty, the slope comparatively steep, and the communication of the water with the sea very easy and rapid, there must be of necessity the chief tendency to floods. The delivery of the water

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 336.

was, after all, a question of time. In the case of the River Nile this was shown in a remarkable manner. It had been discovered that the nearest approach to the sources of the Nile consisted of two vast lakes, which appeared to be fed from the interior of Africa from some mountain chain. From these lakes there issued a remarkably regular stream, which received for a long distance only a small number of tributaries; but amongst them were two of considerable importance entering from Abyssinia: these were both flood streams: they had no flood-regulators, and they brought down with great rapidity those waters which supplied the great mass of mud forming the delta of the Nile. In this river, therefore, might be seen the effect of lakes and swamps acting as flood-regulators, and equalizing the flow of part of the stream, while certain tributaries without such regulators produced a flood at certain seasons.

He had said there were other flood-regulators. There was not only the relative elevation, or the difference of level between the sources of a river and the sea to be considered, but also the mode in which the water-supply was obtained. Some rivers were supplied entirely and directly by rain, which, after falling from the clouds, ran over the surface into natural channels from the commencement; but almost all the great rivers of Europe were partly supplied from vast reservoirs of snow and ice. The water falling as snow instead of rain over large mountain surfaces, accumulating in glaciers, and remaining in the state of ice for the greater part of the year, melting in summer, but only partially and comparatively slowly. These glaciers served as flood-regulators. They were assisted in some cases by lakes, but not in all, and the lake, important in this respect, as it certainly was, required to be considered in connection with the mode in which so large a part of the supply was yielded. The Danube was a great European stream that was supplied only to a comparatively small extent from glacier sources, and it passed through no lakes, though not without swampy ground for part of its course. It was also a river subject to heavy floods, though less so than the Loire and the Rhone; and, in comparing the Danube with other rivers, there appeared to exist important flood-regulators other than those that Colonel O'Connell seemed to admit.

To come nearer home, it was certain that there were flood-regulators in this country in abundance, not only of the kind already alluded to, but others of which there could be no doubt, although not usually recognised. These included the conditions of the strata, —not so much the actual rock at the surface as the position in which the strata lay, and the way in which the water entered the earth and was received into the interior. This took place partly at the place where it fell, and partly over the entire district through

which the river ran. The whole drainage area, moreover, was affected by the rocks which existed underneath its surface. In this respect even gravel, however large the drainage area might be, acted as a flood-regulator, and the various rocks themselves did so too. Such also did chalk, which was highly absorbent, and acted very directly; also the limestone rocks in the middle and west of England, which covered a large extent of country, and acted as recipients of water as thoroughly as the chalk itself did. Limestones did not absorb quite as much; but the quantity of water which sank directly from the surface in limestone districts was very great, and nearly equal to that which disappeared from the chalk. Nor were the sandstones to be despised in this particular; they carried water in many parts to a considerable distance, and passed rapidly from the surface. No doubt the water carried off in this way sometimes came back in the shape of springs, and the springs might affect some other drainage area. No doubt also, among the flood-regulators might be included the geological condition of the land over which the water flowed. These points were important as affecting the quantity of drainage-water going to the sea. The mean proportion of the water falling on the surface of the whole drainage area as rain, and passing out to the sea, was one thing: the quantity of water which flowed during flood seasons was another and a totally different matter: the two must be kept asunder and considered by themselves; and the value of any stream for the discharge of water could only be understood by a reference to both of them. It was thus, as he believed, that the Table accompanying Colonel O'Connell's Paper was valuable, as representing certain important facts determined with regard to the proportion of water in streams that ran off in floods. In preparing it, however, the Author had not entered into any serious calculation as to the general quantity delivered by streams, and the proportion it bore to the rainfall and the extent of the drainage area.

There were many points of interest concerning flood-waters directly affecting engineering, but which had not been touched upon. There were also many questions equally important that suggested themselves at once to the physical geographer, as well as the engineer, concerning the mode in which streams were fed at other times. It was, in fact, difficult to dissociate floods from the general question of rivers or water running over the surface. He further remarked that sufficient attention had not been paid by the engineers and surveyors who had prepared the Ordnance Maps of this country, to the survey of drainage areas, and an estimate of the quantity of water that flowed over those areas, as compared with the discharge where it entered the sea, and at different points of the river. He had investigated that question in some special cases; but it was a matter which should be done for all

the rivers of a country like England. Questions were constantly arising in which these matters came before Parliament, and geologists, as well as engineers, ought to be in a position to give accurate information about them. He might except the Tables prepared by Mr. Beardmore and some others; but there were comparatively few rivers of which enough was known to enable it to be stated positively, within a given collecting ground and a given rainfall, what would be the actual quantity of water obtainable at different seasons, and the actual average and total discharge at the mouth or at any part of the river.

Captain E. R. James, R.E., stated, as an officer employed on the National Survey, that he had, three or four years ago, made a proposal to include within the survey just such information as it was now considered desirable to obtain. He wished, on a separate set of sheets, to show the watershed lines, dividing the country into basins, tributaries, and feeders, giving the areas of all such divisions; and in connection with this survey, he also proposed that rainfall and outfall observations should be systematically taken in each basin, for a period of one year, at the public cost; but the usual financial difficulties were made in opposition to this scheme, and it had not been carried out.

Some years ago, the study of the useful compilations of Mr. Symons on rainfall, led him to conceive that a practical application might be given to those labours, by endeavouring to establish a relation between the rainfall over a river basin, and the outfall from the same basin, in order to show what proportion of the supply of water was available.

He commenced in the year 1864 with the basin of the River Eden, near Carlisle; and his first results, based on very few observations, seemed so strange that he could not trust them. The outfall was found largely to exceed the rainfall.

He determined to be more careful in the next experiment; but the results were still difficult to understand. He chose the upper basin of the River Wey, which had its outfall through the gorge of the chalk hills at Guildford, and its sources on Leith Hill and Hindhead. The watershed line of the basin was strongly marked, and no better place could be found for such an experiment. The area of the district drained was 229·4 square miles; within this district, and on its confines, he had obtained observations from fifteen rain-gauges, placed at altitudes varying from 120 feet to 814 feet above the sea, and so distributed as to enable him to find the mean rainfall very nearly. By continuous observations, from the 1st May to the 31st December, 1867, he found a fall of 18·105 inches, and that the volume of water produced amounted to 9,683,612,200 cubic feet.

During the same period, observations were from time to time

taken of the transverse section and velocity of the River Wey at the outfall at Guildford. At one place one hundred and seven observations were taken; and at another, half a mile lower down the river, ninety-seven observations: from the mean of these the volume of water was calculated at 3,229,919,915 cubic feet in the eight months; thus showing, in round numbers, that $\frac{2}{3}$rds of the rain had been absorbed or evaporated before it reached Guildford. He regretted that he could not place absolute reliance on the gauging of the river, from the fact that occasional stoppages of mills—not to mention floods—would cause the volume of water to vary unequally; but he might take his results as roughly correct, if he added $\frac{1}{4}$th part to the outfall recorded for flood-waste; and even then, the proportion of outfall to rainfall would be as 4 to 10 only.

Now, he had stated that his first experiment in the basin of the River Eden gave a directly contrary result. There, the outfall exceeded the rainfall; and the question was, if any reliance could be placed on his accuracy of observation, how the anomaly was to be explained. He could only account for this by the difference in the respective geological formations of the two basins; and he thought that the probability, in any case, of an abundant supply of water being delivered, on the contrary, must depend upon several considerations:—

1st. The relative porousness of the formations over which a river passed in its course.

Thus the River Wey, rising on the Wealden, and passing over the greensand and the gault, touched on the chalk just as it reached Guildford, and had by that time lost much of its volume by absorption; whereas the River Eden, rising on granitic and primitive formations, passed over mountain limestone, and debouched on the new red sandstone, a slightly porous rock, but more compact than the greensand which absorbed so much from the Wey.

2nd. The inclination of the strata.

If the dip were steep, the separations of the beds of porous and non-porous rock formed so many channels in assisting the subterranean flow, and consequently the absorption at the surface of the water.

3rd. As a corollary to the last consideration, the separations of like strata on either side of the anti-clinal axis, in contiguous river basins, must be regarded as the inlets and outlets of so many syphons; and while one basin was losing its water, the quantity in another was being continually added to. If this were the case, no estimate of outfall based on the rainfall could be relied upon, and the excess in the River Eden, apparently unreasonable, would be partially explained.

4th. The rapidity of the flow of the stream.

The truth of this was, he thought, self-evident, and it would afford one reason why the outfall of the River Eden was relatively in excess of that of the River Wey.

The rainfall being known, the likelihood of a constant supply of water being obtained might be judged on these considerations, and it might be assumed that at least half the outfall quantity was available for the use of man.

Mr. Beardmore could appreciate, from long personal experience, the trouble which attended investigations of this character from the difficulty of gauging rivers accurately. The best example of gauging the flow of a district was that of the Commission Hydrométrique de Lyon. The observations, in continuation of others previously recorded, embraced a period of twenty-four years, during which the height of the Rivers Rhone and Saône was taken daily at several places at and above Lyons, while rain-gauges were kept over the whole area drained by these rivers. He quite approved of the proposition for a more extended and complete system of gauging the rivers of this country, so as accurately to determine their hydrometrical condition; but it must be borne in mind, that facts extending over a few months only would not be sufficient for the purpose. The River Eden and the River Wey were especially affected by the working of mills. During the dry months of summer, the millers stored up the water in the upper reaches of these rivers by shutting down the sluices. This was felt on the Thames: the mills not being worked on Sunday, the water accumulated during that day, and was released on Monday, so that the minimum flow of water generally occurred on Tuesday. Thus, even on so large a river as the Thames, a continuous gauging was rendered necessary. Essays had been written by Lombardini and other Italian hydraulic engineers on the rising of the River Po, when the other rivers that fed it were falling; from which it appeared that, while feeders were discharging into the main river an additional volume of from 10,000 to 30,000 cubic feet per second, the main river appeared to be discharging the same total as before the junction of the tributaries. But rivers like the Po, or the Danube, when getting into a state of flood, were filling up their beds and the adjacent marshes, as well as flowing onward. Thus, in the lower part of the River Mississippi, there was an area of 550 square miles of river-channel alone, above the great swamps, that had to be filled before the river was affected lower down. At the time of flood, the embouchures of the branch rivers were either filled from their own basins, or by the back-water from the main river, which in the Red River during floods, would reach up 300 miles from its junction with the Mississippi; so that it was impossible to say what was the true flood-volume, where it appeared that for days together the

excess of water was accumulating over these immense flats. He had come to the conclusion that the best way of dealing with the problem was to collate the general facts, with reference to the meteorological conditions of river basins. But the rainfall of river basins was rarely correctly ascertained, owing to difficulties in the way of keeping rain-gauges; and this was markedly the case over the basin of the Mississippi. It was well known that the moist winds from the Gulf of Mexico did not reach over a great portion of the Red River and the Arkansas, and that in that region the rainfall was as low, sometimes, as 5 inches in the year. In fact, at many of the outposts of Mexico and Texas, there was hardly any water to drink, while in other districts of the same basin there was an excess of water. This example might be compared with that of the River Loire, or some of the branches of the River Rhone, which rose among precipitous mountains, where the warm moist winds, coming up from the Atlantic and the Mediterranean, were arrested and the vapour condensed in floods of rain, from which arose the sweeping inundations common to those and other rivers similarly situated. He had often recommended that the River Thames should be gauged two or three times a day; and he had suggested as suitable points for the gauging, a spot somewhere in the neighbourhood of Long Wittenham, and another at Staines, so as to enable the volume of the River Thames, and the amount of rainfall over its basin, to be published every week, together with a statement of the condition of the water. He ventured to suggest that the sine of the angle of the general slope of the country ought to form an element in the formula given by Colonel O'Connell, although it was unlikely that any formula would prove strictly consistent with the results of observations, inasmuch as the elements were so variable.

He had taken a good deal of trouble to gauge the River Lee, for the last eighteen years, at a spot on the canalized portion of the river at Hoddesdon, where a pond of large extent afforded an area of water little affected by mills or accidental flushes. A suitable tumbling bay rendered the arrangements easy. It was formed with cast-iron posts about 5 feet apart; the gates were made level and tight, and a gauge was fixed at a distance, so as not to be affected by the flow of the water, with its zero level with the top of the gates. There were nine of these gates, over which a depth of about 15 inches of water ordinarily flowed. Movable boards were available to close each opening at the top, and were taken off or put on as the flow of water diminished or otherwise, and the depth of water on the gauge, and the number of gates over which water flowed, were recorded three times a day; so that the ordinary flow was gauged by overfall, the best method, in a river having weirs, or draw-gates. When the water in the river increased to too great a

volume to be measured over the gates, these were lifted, and the water was allowed to rush through. The levels of the head water above the gates, and of the tail water below, were then recorded together with the number of gates drawn up, and from these data the velocity and volume of the water passing through were computed. The French gauged daily the River Saône, which was without weirs, at a single spot where the channel extended in a long and regular reach, and where, by a great number of experiments, they had ascertained the quantity of water flowing past when the river was at different levels. He believed it possible to ascertain by experiment, from observations at a single gauge, what quantity of water a river was discharging: but not during great floods; for if the river was rising, and the flood was in its first stage, its velocity would be very different from what it would be when the river had attained its maximum height, and had fallen again to the same point. The dangerous part of a flood was during the rise, when its velocity was at its maximum. It was not exactly at the top of the flood that the danger was greatest, but when the difference between the level of the water below and above any constricted part on the line of the growing torrent, was at its maximum. He had measured the velocity of the River Lee in a flood, in November, 1852, when running about 9 miles an hour, a speed that he had not before considered possible. On that occasion 400,000 cubic feet of water per minute came from off a district not exceeding 330 square miles in area. The rain had been nearly constant for nine days previously: the ditches were filled with water, and the soil had become thoroughly saturated; so that when a heavy fall of rain for thirty hours supervened, the water came down with a velocity that had some relation to the slope of the country above it, without much regard to any of the obstructions on the way. This flood carried away a great deal of property; it attacked the Great Northern Railway in one of the flat valleys in Lincolnshire, and passed over marsh banks that had safely protected the land for ages, to the astonishment of the farmers, who attributed the effects to the railway that had then been recently finished. On the same occasion the flood carried away two bridges, on a long embankment of the Northern and Eastern Railway. The river ordinarily made a circuit of about 2 miles, with a fall of 10 feet, distributed over two weirs. The chord of this curve was only $\frac{3}{4}$ of a mile, and when the flood had risen 3 feet above the ordinary limits, the water took the shorter course, which led to where the railway embankment crossed the valley; and although ample waterway was provided on the usual course of the river, the alteration of level directed the body of water with great velocity through two flood-openings, where the fall was concentrated for a short time, and both bridges, railway, and embankment, were overthrown and distributed over the marsh.

In cases of floods recorded by the French engineers, the results corresponded pretty closely. The extreme floods of the River Seine generally discharged 3,000,000 cubic feet per minute, the floods at Paris being as heavy on occasions as any known in a flat country. He might observe in conclusion, that the best way of gauging streams of limited dimensions was by an overfall; next to that was by deductions from the observations of two gauges at different levels; but where, as in the case of large floods, these contrivances were unavailable, averages must be taken of numerous observations of the actual velocities, so far as could be obtained, though, at best, the results would be only approximate.

Mr. Cockburn Curtis considered, that the question of "the relation of the fresh-water floods of rivers and streams to the areas and physical features of their basins" was one of those multiform problems which were of frequent occurrence in the art of engineering, and which could only be solved by special attention to the peculiar circumstances of each individual case. In attempting to form a rule it would be found that there were as many exceptions as rivers, nay more, that the flood discharge in each river would vary according to the precise locality in which it was measured. Consequently, although general rules, incapable of definite expression, might be acquired by extensive and varied practice and observation, he feared that in the present state of hydronomical science, any attempt to subordinate or reduce such rules, or the manner of their modification and operation, to the predictive precision implied by the terms in which a mathematical formula was expressed, would be futile. The Institution was, however, under great obligations to Colonel O'Connell. That gentleman, in the face of the well-known prejudice against mathematical formula which was ordinarily exhibited by practical men, had shown an example of moral courage in not withholding from his professional brethren the conclusions at which, after careful consideration, he had himself ultimately arrived, and while fully admitting the difficulties surrounding the solution of the question, had undertaken the somewhat unappreciated and ungrateful, although useful, task of marshalling and classifying a series of facts for the use of future inquirers. Although Mr. Curtis was not prepared to agree with the Author as to the utility of the modulus M, he thought that the column in the "Table exhibiting the physical Features of certain Rivers," entitled "Flood discharge of the river in cubic yards per second per square mile drained," contained elements which might hereafter be made the basis of a few rough-and-ready rules, and more particularly if a greater number of well-authenticated examples could be obtained and recorded.

Mr. R. Hassard understood from what had been stated with respect to the quantity of water passing down the River Wey, at

Guildford, that it was thought the water which fell on the green-sand was absorbed and carried away by subterranean channels to some district outside the basin proper of the Wey. But he had arrived at a different conclusion. In the years 1850-51, an agitation was set on foot by the General Board of Health, as to the desirability of supplying water to the metropolis from the district known as the Bagshot Sands. Several Papers were published on the subject, and one, by the Honourable William Napier, gave a description of that district, and the results of gaugings. Shortly after he was called upon to examine the district, and report on Mr. Napier's statements and gaugings. He made a great number of gaugings, and, except in three or four cases, in which Mr. Napier had given too high results, from having gauged the streams below mills which were at work at the time, his gaugings agreed pretty well with those of that gentleman. But amongst other districts to which his attention was directed, was the upper part of the drainage area of the Wey, already alluded to. At the time he made the gaugings there had been very little rain for sixty days, so that he was surprised to find in such an apparently sandy waste such copious springs, so much so that he could only account for the abundant yield of water, especially in the eastern part of the drainage area, by supposing that these springs were giving out water derived from rain which had fallen on some district outside the apparent drainage area. He found streams, seemingly supplied from not more than 600 acres or 700 acres of drainage area, yielding large quantities of water. The upper part of the beds of the streams was dry, but lower down the hill a trifling rill appeared, scarcely thicker than the finger, which in the valley below swelled to a considerable body of water. In three or four instances, he noticed that the quantity of water was almost as much as one might expect from a non-absorbent area, of the same configuration, after a smart rainfall. He, therefore, differed from the opinion of Captain James that there was some loss, owing to the existence of the green-sand district. On the contrary, he believed there was a positive gain; and that the water was absorbed, and given out in the shape of perennial springs, which would have been lost under other circumstances.

Mr. G. H. Phipps was at a loss to perceive in what manner the formula proposed by Colonel O'Connell, for the classification of rivers, as flood producers, could be made available to the practical engineer.

Colonel O'Connell proposed to assign to different rivers a certain measure or modulus (called M) of their flood-producing capabilities, such measure being founded upon a certain relation supposed to exist between the area drained by any particular river and the water discharged by it at some point upon its course, the areas

drained being for the purpose of the above comparison deemed identical in the various qualities of declivity, absorption, filtration, evaporation, and rainfall. Now, supposing a table of rivers, duly classified according to the values of M, and that for two of these rivers draining equal areas, under equal amounts of rainfall, the coefficients of M came out as 1 to 2. Then, according to the Paper, this difference might be due to a variety of circumstances, such as the comparative difference in the capacities of the rivers, the presence of lakes, the sharper declivity of the surface drained, the greater absorption of the soil, the difference of evaporation, or the proximity of melting glaciers or snow, &c., any one or more of which causes would be sufficient to account for the difference in the value of M; then the question which naturally arose was, To which of the above qualities ought the want of coincidence in the value of M to be attributed? and whether, as many difficult observations of the physical characters of the districts would not be required to determine the reason of the want of agreement in the values of M, as would have sufficed to give the requisite information without the assistance of modulus M at all?

The above questions appeared naturally to arise, however accurately the value of M might have been deduced from the premises of area drained and water delivered: but he confessed, that after a careful perusal of the Paper, he could not comprehend the reasoning of the Author, as to the quantity of water delivered by large rivers being in the proportion of the square roots of the areas drained, abstraction being made of all varying physical features of the districts compared; for after such abstraction, it certainly appeared more reasonable to suppose, that whilst the rapidity of rainfall remained the same, the theoretical delivery ought to be rather in direct proportion to the areas drained, than to the square roots of such areas. He was quite aware that the actual delivery from varied areas did not increase in proportion to those areas; but he thought this more probably attributable to an erroneous assumption of uniform rainfall over large districts, where it was impossible to ascertain the existence of such uniformity, rather than to the inability of varying areas to deliver quantities of water in proportion thereto.

Colonel J. T. Smith said, with regard to the rainfall in Southern India, he remembered, on one occasion, during the morning service in church, a rainfall of 8 inches; and during the hurricane at Madras, in 1846, no less than 21 inches of rain fell in the twenty-four hours.

It had been well said that the modulus M was too wide and comprehensive to be of much use. In order to make it useful, it must be taken, split into parts, and each part valued. Doubts had been expressed as to the accuracy of reckoning the retarding influence in the ratio of the square root of the length of the line

of drainage. To the best of his recollection, the Author did not say the flood was in the proportion of the square root of the line of drainage. He could not mean more than that it was as the square root of the area. It had occurred to him as the possible explanation, that, supposing the area of the basin to be a true square, so placed that the diagonal formed the line of drainage, it might be assumed that the amount of accumulation, constituting the greatest flood, would depend upon the rapidity with which the water flowed down that line, and that it would be inversely as the length of the diagonal, that was, inversely as the square root of the area; and as the whole amount of water falling on the catchment basin would be directly as that area, the combination of the two, viz., $\frac{a}{\sqrt{a}}$, would cause the result to be as the square root of the area. He might add that Colonel O'Connell's was not the only formula that had been put forward. There was another, proposed by an Indian officer of experience, which was founded upon a different assumption, that the maximum flood was as the fourth root of the area; and it had been found to correspond with the facts pretty well. The formula was a simple one $Y = 825\ a^{\frac{3}{4}}$, where Y represented the maximum flood in cubic feet per second, and a the area of the catchment basin in square miles. There were five or six elements into which this modulus M should be broken up. The first was the comparative area of the rainfall to the area of the water-shed; because in such a case as that of the Mississippi there was an area of 1,244,000 square miles. Extensive showers occurred in England, but in other parts of the world vast storms had to be provided for. He had seen something like evidence of a rainfall that had affected an area of 50,000 square miles. But in regard to the largest areas, not only ought the area of the basins to be considered, but the comparative area of the rainfall also. Another point was the structure and general character of the surface; another, the form of the area. Then, further, there was the amount of rain; also the continuance of the rainfall; for if it lasted but a short time in a very large district, the maximum flood could not occur; then there was the general shape of the basin; and, lastly, allowance must be made for the quantity of the perennial flow. If these points were attended to, it would be possible to ascertain something like a fairly correct, though rough estimate of the maximum flood, and that was all the engineer wanted.

Mr. R. P. Brereton said, there was no doubt the assumption should be, that a certain number of rivers flowing down to a certain coast line would practically drain parallel areas; as a river would have to drain an average of half the distance between itself and its neighbours. As the river increased gradually as the quantity of

water increased, it would seem that if the quantity of water falling in the valley basin was the same along its whole length, it would require four times the inclination to discharge the quantity from double its length, assuming no increase in the size of the channel. That would give the form of curve described. But it was assumed that the size increased in the same proportion as the other elements, so that it did not appear why the form should differ from a straight line. The curve really formed by most rivers was concave instead of convex; and this was consistent with a river larger at the mouth than at the source. Colonel O'Connell's Paper was valuable to the statistician and physical geographer, who would read a collection of facts and theories based upon them; but as a practical Engineer he did not see how, in attempting to mitigate disastrous floods, he should be able to do so by the application of the formula in the Paper. Neither the height nor extent of floods could be ascertained except from the 'oldest inhabitant,' or some such authority. If these Tables would enable the floods of the River Thames to be calculated from the mathematical formula of floods in the River Severn it would be useful to the Engineer; but he did not believe any amount of mathematical reasoning would be applicable to any one particular case. On the subject of gauging, nobody knew what amount of rain actually fell anywhere. He had lately seen water-spouts in this country, which he had not previously believed in. He had seen them fall within 100 yards of him without being wetted by them. If he had had a rain-gauge there and recorded nothing he should have astonished everybody; but if the water-spout had fallen upon a rain-gauge the result would by many have been received as incredible. Lakes were described as flood moderators. It might be inferred from this that in attempting to mitigate floods lakes should be created for the purpose; but lakes could only act as flood moderators after their ordinary water-level was exceeded. Up to that time they were permanent floods themselves. The dried-up bed of a lake would be a better moderator of floods than if it were full of water.

Mr. C. Vignoles, Vice-President, remarked that Mr. Brereton forgot that one of the methods proposed by the French engineers for obviating the perils of the floods in the Rivers Saône and Loire was the formation of a succession of lakes in the villages.

Mr. Brereton.—Then they should have no water in them. When it was said a lake was a flood-moderator it was not so, it being merely a pool of water. Again, it was stated that dense forests, although flood-moderators, had sometimes apparently the property of increasing the amount of rainfall, &c. In England floods were on the whole more beneficial than otherwise. In other countries of Europe he had seen and heard of the effects of disastrous floods—augmented by the removal of forests from the

mountainous districts. The crops in the valleys had been carried away for miles in extent, and the ground covered with débris; but in the district of the Apennines and elsewhere, the foliage and roots of trees on the mountain sides had been the saving of the cultivated grounds in the valleys. The only way he could suppose that forests were producers of floods was, that high trees on summits might intercept clouds and bring down rain that might otherwise pass off; but the saving of so small an amount of rain could not at all compensate for the destruction of the forests.

Mr. W. Parkes agreed with those who argued that the value of the suggestion thrown out by Colonel O'Connell was not to be measured by the practicability of applying it immediately to any particular case. It appeared the object was to suggest a means of determining some relationship between facts which would otherwise be entirely isolated. Whether any particular facts were in conformity with this supposed theory, or exceptions to it, he thought was at present a secondary matter: the theory afforded a means of bringing the facts together, and thus giving to each individual fact a value which it would not have if it stood alone.

A good deal had been said about 'flood-moderators:' he did not know whether that term was to be found in the vocabulary of science; but it was one of which the general meaning was easily understood: at the same time he thought a more strict definition was desirable. There were two classes of causes which affected floods, both included apparently in the term 'flood-moderators.' One class of causes was that of which the effect was to abstract the water brought into the channel of a river and carry it off by some entirely different means, either by evaporation, filtration through permeable substrata into some other drainage area, or absorption by the soil itself, which would retain it till the flood of the river had passed away. That was one kind of moderator, to which in one sense the term might no doubt be properly applied. Another class of causes was that which did not diminish the quantity of water which flowed off by the channel of the river even while in flood, but only lengthened the duration of its discharge. In other words, a flood which at one place would take one hour to flow off would, after having been subjected to the action of the 'moderator,' occupy two hours in another place, and thus the maximum rate of discharge in any one short period of time would be considerably reduced. He thought these two kinds of moderators should be kept distinct in the mind. Of the two classes of causes that which acted by abstracting the water from the river altogether was the more difficult to bring under any rule. He had mentioned two or three modes by which water might be actually abstracted from the rivers while in flood, and there were probably others of a more recondite character, the effects

of which might easily escape observation in an ordinary case. He happened to be acquainted with a district in which the effect of floods was manifested in a remarkable way. That was the district which drained into the Lake Fucino, in Southern Italy, and which would no doubt be remembered in connection with an interesting project for draining the lake, commenced by the Emperor Claudius. By the last accounts he had received, six or eight years ago, the works were on the eve of completion; but at the time he visited the place, the engineers had fitted up a temporary residence in one of the shafts of the tunnel to get out of the way of the brigands. It was, however, with the physical character of the district, and not with these works, that he was now concerned. The lake had the peculiarity of possessing no visible outlet: there were no doubt subterranean outlets, but they were of limited capacity; and the effect of the floods in the surrounding district was simply to raise the level of the lake. The lake itself had an area of about 50 square miles, and the drainage area, though very undefined, might be approximately stated at about 300 square miles. The district was mountainous, and a great part of it was, from six months to nine months of the year, covered with snow. During the spring the snow melted on the mountains, and, flowing down, caused the lake to rise. Evaporation and the constant flow through the subterranean outlets caused it to fall in the autumn. So far, everything was quite natural. But beyond this there was an effect which he had never been able to account for satisfactorily. It was this: for a series of years the lake continued to rise, and then for a series of years continued to fall. Between the years 1816 and 1835 the lake fell 40 feet: the fall was continuous from year to year. There were alternations of rise and fall at different seasons, due to the melting of the snows; but on comparing corresponding seasons in consecutive years the fall was continuous. During the succeeding nineteen years, from 1835 to 1854, there was a continuous rise of the lake, which in the latter year was still in progress. Between 1835 and 1854 it rose 20 feet. What was the state of it at the present time, or indeed whether there was any lake at all, he could not say. The question was, what could be the cause of this continuous rise and regular fall over long periods. He confessed he could not account for it; but it was possible that there were analogous cases in some districts of this country, where similar causes might be at work, though as they would result in passing floods, the particulars of which would not be so easily observed as would be the changes of level of the lake, they might pass unnoticed. The formation was limestone, with the usual characteristic fissures and cavities, and with springs issuing from them with a discharge nearly constant all the year round.

With regard to the escapes also from the lake, a curious fact

came to his knowledge. He was told of the existence of a subterranean river known to be flowing away from the lake, called La Petogna. He went to the place where it was said to escape into a large fissure in the rock, but it was nowhere to be seen. There was deep water alongside the cliff, and long weeds growing up from the bottom of the lake. These weeds by their vertical position indicated perfectly still water, and there was no other sign of any current towards the alleged subterranean escape. Subsequently, the lake fell, and then rose again; and it was still rising some months after the search previously described, while he was one day called to see La Petogna in action. There was then a considerable volume of water flowing into a fissure in the rock. The flow continued for several days, and then gradually ceased. It was not difficult to account for this phenomenon by supposing that the water was carried into a subterranean cavity, from which there was a small outlet at the other end at a lower level into another drainage district. This cavity would be quickly filled and slowly emptied. When the latter fell away from the inlet, the cavity would be slowly emptied, and when it rose above the inlet, the cavity would be quickly filled again. These were facts which it was impossible to bring under any rule. The subterranean cavities and fissures by which the water escaped could not be found, and their existence seemed to frustrate every kind of attempt to bring these phenomena within any law.

So much with regard to one kind of flood-moderator, that kind which might perhaps be better called 'abstractor.' With regard to flood moderators proper, he thought there was a better chance of dealing with them, as they depended upon conditions which were more easily ascertained. Something had been said about the effect of lakes. He thought not only lands occasionally overflowed, but pools which were constantly full were decidedly flood-moderators, and he was not sure whether the latter did not act in this respect better than the former. Suppose a heavy flood was thrown down at a certain point into a river-bed, and continued for an hour. At a point 10 miles lower down would that flood pass off in an hour? Under certain circumstances it would, but under other circumstances it would be three or four days. He thought a lake in some form would make just that difference. The effect of a flood flowing into the head of a lake was to raise the water, and the discharge of water at the other end was regulated by the degree to which the water was raised, and the capacity of the outlet with that increased depth. The rate of discharge of the flood from the lake was, therefore, in a great measure, independent of the rate at which the head of the lake had received the flood. Thus, the duration of the discharge would be lengthened, and the rate consequently moderated, according to the physical features of

the lake itself. There was another way in which the lake served as a moderator of flood. It hastened the discharge of the early part of the flood, in addition to retarding the later part, and thus in both ways increased its duration. It was the same with a pounded river, which it was admitted had the effect of passing off floods more easily than an unpounded one. The effect was thus accounted for:—When a flood was passed into the head of the lake, or pound, the discharge at the other end was brought about not by the water actually passing through the whole length of the lake, or pound, but a wave was propagated through the water, and when that wave was felt at the lower end the discharge commenced. A simple calculation would show, that in an ordinary case this would take place sooner than if the water had to travel bodily over the same distance along a river-bed previously dry, or nearly so. Take a distance of 10 miles from A to B. If the river-bed were dry, or nearly so, as water would not flow faster than 5 miles or 6 miles an hour, it would require something like two hours for the first of the flood-water to travel from A to B. But if the length A B were occupied by a lake 18 feet deep, then the discharge would commence in such time as was necessary for the wave to be propagated from A to B, over a length of 10 miles of water 18 feet deep, or at the rate which a body would attain in falling through a space equal to half the depth of the lake, that was, $(8 \times \sqrt{9}) = 24$ feet per second, or 16 miles per hour. Thus, the flood would commence at B about forty minutes after it had reached A, and nearly an hour and a half would be gained for the duration of its discharge at B.

Mr. R. W. Graham thought Mr. Howden's Paper described very fairly, and without exaggeration, the extent and effects of the floods in the Nerbudda Valley. The irregularity and the fluctuation of the floods that occurred in India were points which would be at once noticed. It was true the Paper more especially referred to the feeders of the Nerbudda, which, though considerable rivers in themselves, had only a comparatively small drainage area. The same fluctuations, however, were observable in the main rivers. Mr. Howden stated that in the River Nerbudda the ordinary monsoon level of the water rose from 30 feet to 40 feet, and he had known it to rise nearly 60 feet, which was an extraordinary addition to the ordinary flood. He had a better personal acquaintance with the River Taptee, a river crossed by the same railway, and nearly of as great magnitude as the Nerbudda, and larger where the railway crossed it than in the higher regions which Mr. Howden referred to. The river rose in the Sautpoora Mountains, and one of its great feeders drained the western and south-western slopes of those mountains. Some thirty years ago in that large river, commanding an immense drainage, there was an extraordinary and

exceptional flood. It reached villages which hitherto had stood high and dry above its banks, and occasioned serious loss of life, both in men and cattle. It was his duty, in the year 1854, while engaged in the preliminary survey of the Great Indian Peninsula Railway, to inquire into the heights of the floods, while the record of that flood was fresh in the memory of the villagers, and they pointed out marks on the temples and houses where this flood had reached; therefore it was an authentic record of a great flood; and that flood was 28 feet higher than any previous flood within the recollection of any villager, and at least that much higher than any since recorded. It seemed that there was no immediate local cause to account for such an exceptional flood, and he supposed the only way of accounting for it was from some exceptional distribution of the rainfall of the district. Generally there were great rainfalls over certain parts of the district only, whereas it was probable in the year referred to there had been an extensive rainfall over the whole district. That this partial rainfall was not an exceptional occurrence in India was evident from the fact, that where the heavily-laden clouds brought up by the south-west monsoon struck against the Western Ghauts they discharged their rain in a short distance, while beyond there was comparatively little rainfall. Thus, on the Western Ghauts, which the Great Indian Peninsula Railway traversed at the Khandalla and Egutpoora stations, there was a rainfall of 160 inches, to 180 inches, whilst at Poonah, within a distance of 40 miles of the former, and at the same level, the fall was only about 21 inches; and at Nassick, a distance of 30 miles from the latter station, the fall was only 26 inches. Therefore, he assumed that in different portions of the same drainage area there were very unequal rainfalls; but that occasionally, as at the time of these extraordinary floods, there was an excessive fall over the whole district. Whether his conjecture were right or not, it was a fact that in India these exceptional floods did occur, and he imagined they would exercise a disturbing influence upon the modulus M.

In the plains, where in the dry season there was not a vestige of any watercourse, but which during the floods gave more trouble than anything else, the cultivation was for the most part rice, and the cultivated plots were enclosed by small dams or bunds, to keep the water up during the time of planting. In the dry season these plains of rich soil were broken up into deep fissures by the extreme heat of the sun, and when the first fall of rain came, these acted in a remarkable manner as flood-moderators. No water came into the main drainage of the district, until these deep fissures were filled; but as soon as they were filled the water began to pass off. The little dams he spoke of held back the water for a time; but with a heavy rainfall, such as 10 inches

in eighteen hours, not only the flow due to that, but all that was held up by these reservoirs, burst away and came down with terrible force upon any construction that crossed the plain on a comparatively level position. That had occasioned considerable damage to the Great Indian Peninsula Railway. To any one who might have to design works for such a position in India, the only remedial plan he could suggest was to have ample provision of water-way distributed frequently along the banks to prevent any great weight coming upon them.

The great floods in the large rivers, and the peculiar circumstances attending the surface floods on the plains, appeared to him a condition of things, in India at all events, that defied all formulæ. No doubt the attempt to establish formulæ, and to lay down given laws, was interesting, and might be useful; and he thought Mr. Howden's Paper, read in connection with that of Colonel O'Connell, was not ill-timed, if it pointed to the necessity of actual observation and investigation in each particular case as the only safe guide.

Mr. G. P. Bidder, Past President, said he had a sort of instinctive feeling against formulæ. His remarks must, therefore, be taken with the qualification, that for all practical, commercial, and mechanical undertakings he had a decided objection to formulæ; and he would say no man ought to use a formula who could not make one, and then only for use as a *memoriâ technica*. The question under discussion was one which affected the supply of water to towns, as well as the provision of adequate water way in railway works liable to be influenced by floods; but if it was necessary to ascertain the facts before propounding a formula, he thought it would be possible and preferable then to dispense with the formula. The history and constitution of rivers was a subject full of interest, although attended with some difficulties; the Papers read on this occasion had somewhat advanced the question, but he hoped they would lead the way to other communications which would render it complete.

With regard to the possibility of establishing any fixed modulus or rule, for defining the flood-producing capabilities of any district, it had been suggested that the volume of water flowing off an acre of ground in one second of time might be calculated, for the steepest districts, from the formula $5\,a^{\frac{2}{3}}$, in which a represented the area in acres; and it was said that, as the land became flatter, the coefficient 5 would have to be varied to 4, 3, $2\frac{1}{2}$, or 2. This was a question which, it was asserted, a competent engineer could soon settle; but, having ascertained the means of settling that question, Mr. Bidder did not think a formula would be wanted at all. When the maximum flood and outfall of a district had been determined, nothing more was required, as the bridges and waterway must be made conformable thereto, whether in accordance with

the formula or not; but the coefficient might have to be varied to a greater extent than from 5 to 2, as in some instances it would be nil. Colonel O'Connell's Paper pointed out a great number of moderators,—such as areas, lakes, intervention of rivers, and a variety of effects which resulted in moderating the overflow of the river; but beyond all these things there were others which they all knew of; for instance, there was the nature of the soil, and not only the nature of the soil, but the nature of the stratification, and the period of the year at which the rain fell. He knew very well, as a simple observer, that an inch of rainfall in summer was a totally different thing from an inch of rainfall in winter; for it was within his experience that of an inch of rainfall in summer, none ever went into the river, while half an inch of rainfall in winter had all run off the land. The result of all these things was that, instead of depending upon formulæ, they had better depend upon patient, quiet, and observant inquiry, especially when they had to deal with a formula in which the coefficient varied from 5 to 2. Such a formula as that was something like Captain Cuttle's watch, which, if it was set forward one hour in the morning, and was put back half an hour at night, would give unqualified satisfaction.

He had had to deal with these questions, in connection with the flood outfall for railway bridges; and especially as Consulting Engineer of the Scinde Railway, he had to report upon bridges in India. That railway, he might remark, passed through a district in which ordinarily the rainfall was very slight, and the river courses were occasionally altogether dry. But in 1866, the river-beds, previously all but dry, became torrents, villages were destroyed, bridges were washed away, and large iron girders were carried half a mile from their site. He made that statement from official reports furnished to the Company. No formula would apply to that case, and records were liable to mislead, for the last village destroyed was a village of refuge, not from ordinary floods, but from extraordinary floods; but a fall of rain came and caused a flood which washed away that village, and the débris carried down by the flood destroyed the bridge over which the railway passed. Therefore he said to attempt to make bridges or reservoirs upon a formula was a delusion. He had no objection to a formula as a *memoriâ technica*, but, for all commercial questions, such as the supply of water or gas, formulæ were, he repeated, delusions. The consumption of gas might be one thing in England, and quite different to what it was in Scotland, or Norway, or Denmark. Before advising any outlay in the construction of works, the Engineer was bound to inquire into all the peculiar circumstances to which the works had to be adapted. The report he had made to the Directors of the Scinde Railway Company, with regard to the flood of 1866, was as follows:—

"24, *Great George Street, Westminster, S.W.*
"*April* 23*rd*, 1867.

"SCINDE RAILWAY.

"W. P. ANDREW, ESQ.

"DEAR SIR,

"I beg to acknowledge the receipt of a copy of a report by Messrs. Harrison and Newnham, dated 18th January, upon the damage to the Scinde Railway caused by the rainfall of 1866; and, in accordance with your request, beg to offer a few remarks upon the same, and on the principles upon which I think provision should be made for guarding against the destructive effects of future floods.

"I must remind you that, on several previous occasions, you have directed my attention to the subject of exceptional floods, and that, in my reports of the 20th October and 3rd December, 1862, and of 7th March, 1865, I have alluded to the want of reliable data, and to the importance of obtaining additional information in reference to rainfall, its maximum rate, areas of distribution, &c., and stated my opinion that it would be better to incur the inconvenience of a temporary suspension of the traffic than to be involved in an uncertain and perhaps excessive outlay for the purpose and object of securing sufficient waterway by means of bridges, for the passage of exceptional floods.

"Since 1862, rain gauges have been sent out in connection with the Indus Valley Survey, and have been established, not only between Kotree and Moultan, but also at the stations of the Scinde Railway; and from them and the observations taken at Kurrachee since 1852, and tabulated in Mr. Brunton's report to Mr. McNeill, on the Scinde Railway Extension, dated 4th October, 1866, some valuable facts have been obtained.

"The views I have just indicated have received confirmation from these results; especially those of the rainfall of 1866; and I beg to draw attention to the following extracts from the records of the gaugings at Kurrachee for the following years:—

Year.	Rainfall in Inches.	Maximum Fall in One Day.	Date.	Remarks.
1852	7·79	2·82	Aug. 10	
1853	6·29	3·08	July 31	
1854	6·71	1·86	Feb. 16	
1855	12·28	3·50	Jan. 7	
1856	1·69	0·45	Aug. 21	
1857	11·33	3·15	Aug. 12	
1858	5·31	2·57	July 17	Scinde Railway commenced April, 1858.
1859	5·28	1·64	July 22	
1860	2·09	0·99	May 15	
1861	5·30	2·06	Aug. 25	Scinde Railway completed May, 1861.
1862	4·02	1·21	July 31	
1863	13·52	4·88	July 10	
1864	4·83	1·07	July 21	
1865	6·12	1·87	Jan. 29	
1866*	12·91	7·40	Aug. 5	* To 30th September.

From this it will appear that even as regards the total fall in each year, the fluctuation is very great—varying from 1·69 inch in 1856 to 13·52 inches

in 1863; but the fluctuations in the rainfall at some of the interior stations have been much greater, for example: in the years 1865, 1866, during which periods only we have observations at these stations, the rainfall at Dorbajee was, in 1865, 4·87 inches, in 1866, 44·67 inches; and at Joongshaie, was, in 1865, 9·60 inches, in 1866, 44·27 inches; thus, while at Kurrachee the rainfall, in 1866, was rather more than twice that in 1865, at Joongshaie it was more than 4½ times, and at Dorbajee more than 9 times that in 1865.

"But as I pointed out in my letter of 3rd December, 1862, it is of far more importance to find the maximum fall in a given time than the average of the year, and the rain gaugings since obtained will illustrate this fact in a striking manner.

"Referring for a moment to the Kurrachee table, in which the total annual fall is so small, it appears that in 1853, 3·08 inches fell on 31st July, out of a total of 6·29; in 1855, 3½ inches on 7th January, out of 12·28; in 1857, 3·15 inches on 12th August, out of 11·33; in 1863, 4·88 inches on 10th July, out of 13·52; and in 1866, 7·40 inches on 5th August, out of 12·91, the total rainfall up to 30th September of that year; but this is far surpassed at other parts of the line. Thus, at Hyderabad, in 1865, out of the annual rainfall of 15·88 inches, 13·41 inches fell on the 5th, 6th, and 7th August, of which 10·24 inches fell on the 6th.

"In 1866 the results are still more exceptional. Thus at Dorbajee, out of a total fall of 44·67 inches, 36 inches fell on the 4th, 5th, and 6th of August, of which 20 inches fell on the 4th, and 14 inches on the 5th; and at Joongshaie, out of 44·27 inches, 32·22 inches fell on the 5th and 6th August, of which 19·1 inches fell on the 5th, and 13·12 inches on the 6th.

"I regret that no returns exist relative to the year 1862, except of the rainfall at Kurrachee, because considerable damage was done to the line in that year, and it was represented as one quite exceptional. There is no doubt, however, that the rains of 1866 far exceeded those of 1862; and I mention them in connection, because an extensive provision of increased waterways involving an estimated expenditure of nearly 75,000*l.*, founded upon the requirements of the rainfall of 1862, was submitted for the approval of the board, which, if carried out, would most certainly have failed to meet the exigencies of the floods of 1866, while a large outlay would have been incurred with little practical benefit.[1]

"Similar proposals appear to have been made on a still more extended scale quite recently; but I fully concur in the limitations recommended by Messrs. Harrison and Newnham, in the report submitted to me; for this reason mainly, that the circumstances are so exceptional in their character.

"As an illustration, I will instance the Mulleer Bridge, of which eleven spans were swept away, the water rising to the girders: now this was not due to the height of the flood merely; for it appears that a village situated more than a mile above the bridge was first washed away, and the débris then carried down and piled against the structure occasioned such an obstruction to the progress of the current as to cause the catastrophe.

"This fact proves, first, the exceptional character of the flood; for it is very improbable that a village would be built and maintained in a situation exposed to so patent a danger. Indeed, I am informed that from time immemorial it has been resorted to by the inhabitants of the Mulleer Valley as a place of security during floods. And, secondly, it affords a reasonable cause for the destruction of the bridge, against which it would

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"[1] In proof of this I may mention that from the correspondence it appears that in 1862 Mr. Newnham calculated upon a maximum fall of 1·1 inch per hour, while in 1866 it amounted to 3 inches per hour."

be hardly possible for an engineer to guard by providing any reasonable amount of waterway; and I feel bound to express my opinion that I do not think that the proposal to raise the girders at this bridge 6 feet, and at other bridges 2 feet 6 inches and 3 feet, will effectually prevent similar disasters in future.

"It is most desirable that the foundations of the new piers should be put in to a greater depth, and that some protection in advance of the cut-waters in the shape of starlings on the up-stream side be provided for the purpose of guiding trees and other floating débris brought down by the current through the openings; but beyond this, I am of opinion that relief for the flood waters across the line should be provided by lowering the embankments to the surface at properly-selected places, protecting at the same time the surface exposed to the wash of the flood by stone pitching or other suitable material. The abundance of stone along the line affords facilities for carrying out this mode of protection, and I think that it should be adopted wherever scour is to be apprehended.

"In reference to the embankment from 29 miles 20 chains to 33 miles, which it is proposed to raise 3 feet for 3¾ miles, at a cost, including two bridges, of 13,000*l.*, I think that before so serious an outlay be incurred it should be well considered whether lowering the line, as suggested above, and as has been successfully done at Pipri, would not accomplish every purpose, and at a moderate cost.

"In the other suggestions of the report, being in accordance with the views I have expressed above, I of course concur, but in regard to the proposed enlargement of the minor bridges and culverts, I can only speak in general terms, as so much depends upon local circumstances: the general principles which I would lay down being that wherever drainage areas of considerable extent are intercepted by the railway embankment, and the fall is towards the railway, the banks should be lowered, where practicable, for the passage of a wide stream of flood water at a small velocity, the surface being protected from scour by stone pitching; and in reference to the bridges, that the girders be placed at such a level as to allow ordinary floods to escape beneath them, but constructed with suitable provisions for encountering the passage of extraordinary floods, and permitting them to pass through and over them.

"By adopting this course it is quite possible that on the recurrence, at perhaps very remote intervals, of such floods as those of last year, the traffic may be suspended for a few hours at some places on the line; but on the other hand the line will not be required to be closed for weeks for repairs; the possible damage will be slight and to a great extent independent of the magnitude of the rainfall; and the primary outlay, and that for maintenance, kept within moderate limits.

"Any attempt to fit the amount of waterways to the probable requirements of future extraordinary floods will inevitably involve the certainty of a very large outlay, and the uncertainty of success as a final result; for after providing increased waterways, raising the bridges, and also the height of the banks, with a view of forcing the floods through the openings, as has been proposed, I am of opinion that the recurrence of a flood similar to that of last year, bringing down wreck with it, may still occasion a similar catastrophe; whereas by adopting the alternative I am advocating, a great saving of immediate outlay will be effected; and beyond a short stoppage of the traffic at extremely rare intervals, no other inconvenience can reasonably be expected.

"In conclusion, I think it only due to Mr. Brunton to say that, looking to the experience which he had during the construction of the Scinde Railway (the rainfall at Kurrachee, as shown by the table during the three years the line was under construction, barely exceeding 5¼ inches per

annum), and other information which he could command, it does not appear to me that any blame can fairly attach to him arising out of the late extremely exceptional catastrophes; I should rather have been disposed to criticise, had he proposed to incur, or had he incurred, the enormous outlay which would have been required to insure the line against any possible contingency, of a magnitude approaching that of the flood of the last year.

"I am, dear Sir,
"Faithfully yours,
(Signed) "GEO. P. BIDDER."

Mr. J. F. BATEMAN was an utter disbeliever in formulæ and coefficients applied to subjects which could not be measured. A coefficient for the discharge over weirs or through pipes might be applied with accuracy; but when rivers had to be dealt with, where the volume of the floods was necessarily uncertain, being influenced by a thousand circumstances, such as the physical features and character of the soil, the character of crops, the declivity of the river, the fall of rain, and many other circumstances, it was quite impossible to apply any coefficient by which the magnitude of the floods could be determined. He was, however, a believer in reasonable deductions from accumulated facts, such as maximum rainfalls and maximum floods, and such records were particularly valuable to the railway Engineer when he had to make arches for the passage of such floods; but a sufficient number of facts and data had not been accumulated to justify conclusions to be worked out by formulæ. Mountain districts sometimes yielded floods of considerable magnitude from limited areas; but in the case of greater areas, even if mountainous, the rain might not be falling in one portion of the district as much as in another, or it might be falling over the whole district at the same time. In some cases, as in that of the River Shannon, in Ireland, a river which was moderated by lakes and extensive plains of bog land, the quantity of water might be deduced with tolerable accuracy, because the discharge was governed by Lough Derg and Lough Rea—lakes 20 miles or 30 miles in length; but with regard to the River Thames, considering the absorbent character of the upper district, and the non-absorbent character of the lower district, as also in the case of the River Severn, no coefficient and no formula derived from previous observation could be applied. All that could be done was to ascertain with accuracy the amount of rainfall, and more particularly the maximum volume of the floods when they did occur. It was difficult to measure a great flood with accuracy, except in a channel of given dimensions, which could seldom be found in a flooded river; but where with any approximation to accuracy observations of that kind could be obtained, they should be recorded and stored up for the guidance of those to whom they would be of value and importance. By the

record of such observations, and the application of ordinary reasoning to them, some useful results might be elicited. In fact, they could be the only guide in many of the points which Engineers had to determine. Therefore, though he deprecated the attempt to apply dogmatic formulæ, which were almost always fallacious or delusive in matters of this kind, he at the same time hoped observers like Colonel O'Connell would continue to accumulate information, in such a way as that it might be reasonably concluded that rivers of a certain character in certain districts would produce certain floods. No formula founded on insufficient or uncertain data was wanted but only facts, and to elicit the truth facts must be acquired.

Sir W. Denison protested against hasty generalisations, in other words, attempting to infer from a few isolated facts a general formula applicable to all the rivers of the world; and he concurred in the necessity for numerous steady observations on this subject. A few isolated facts that had come under his own observation in Australia and India tended to bear out what he had said. There was a bridge to be built over a river in Tasmania, and inquiries were made as to the maximum floods: the information given was very specific that the maximum in twenty years had been up to a certain point; and the bridge was placed 6 feet above that highest known flood. The next year the flood went 6 feet over the bridge; so that the mean rainfall had nothing to do with the height of the maximum flood. Information as to the maximum rainfall was wanted, and that was the kind of information which it was difficult to get. Then with reference to the character of the soil, as affecting the amount of water discharged at the outfall, observations were made for the purpose of providing water for the supply of the city of Sydney. For six months or nine months the rainfall was gauged over a large area; the outfall was also gauged, and it was found that, on an average, only about one-fifth of a rainfall was discharged at the outfall. To mention another instance, the Madras Irrigation and Canal Company had the command of the Toombuddra River, partly for irrigation, and partly for navigation. One of the schemes proposed was to make a dam across a valley, so as to retain a portion of the rainfall of the south-west monsoon, and to draw it out in the dry season for the supply of the canal. The Engineer made his observations; and calculating that three-fourths of the rainfall would be discharged at the outfall, he proposed to construct a dam 150 feet high. But the Government was not satisfied with the correctness of the data, and directed, very wisely as it proved, that the outfall should be gauged. This was done during two consecutive monsoons, and it was then found that the whole of the water discharged at the outfall could be retained by a dam 50 feet high. He did not believe that the facts which related to one valley were at all applicable to another. Each place must be

judged on its own merits: the character of the soil, and the form and stratification of the ground must be studied. It was sometimes found, as was the case in Australia, that the rain flowed off a mountain district very rapidly, and caused a river of 60 feet or 70 feet in the stream through the flat land below the hills. It was, of course, inexpedient to go to the expense of raising the bridges 60 feet or 70 feet; so the bridges were built for the express purpose of allowing the flood water to pass over instead of under them, and he had seen the floods rolling over these bridges for three or four days together from 20 feet to 30 feet in depth. It was true that the roadway was rendered impassable for a short time, but this was, in that country, but a trifling inconvenience, when compared with the cost and the risk which would be incurred in building bridges to span such a torrent.

Allusions had been made to the effect of forests upon the rainfall: a curious instance of this action was to be seen in India. The Western Ghauts, which ran parallel to the coast of the peninsula at a distance of from 50 to 60 miles, had a break in them of about 40 miles in width, through which the railway from Madras to the west coast was taken at a level of about 1,200 feet above the sea. About 20 miles below the crest of this slope the railway left a dry, bare-looking country, and dashed at once into a rich-looking bamboo jungle, where the vegetation was most luxuriant. Upon inquiry, it was found that, although the south-west monsoon passed with full force through this gap in the range of hills, the rain stopped at this line of jungle; that at a few hundred yards to the west of the line there was probably a depth of 60 inches of rain or more in three months, while at the same distance on the east side of the line there was not a depth of 6 inches. Different explanations were given by various meteorologists and others, but none of them were satisfactory. At length a reference to the collector of the district elicited the fact, that the line of no rain had travelled backwards a distance of 7 miles in the course of twelve years; that when the forests were cut down, and the ground laid bare to the action of the sun, the rain ceased. Upon reflection, it would be easily understood that this must be the case. The sun during the south-west monsoon was almost vertical, and it shone down upon the bare dry soil, creating by the radiation and reflection of its heat an upward stream of hot dry air, which encountering the rain, turned it into vapour, which was carried away by the south-west wind, bestowing here and there a shower when it passed over forest land, but never descending again in any body till it reached the Bay of Bengal. The same cause would produce the same effect in all countries similarly situated, but it would not be safe to lay it down as a general rule applicable to all countries, that the consequence of destroying the forests would be followed by similar results.

Mr. John Brunton stated, with reference to the floods in Scinde, that the register of the rainfall was taken from gauges sent out from this country by the Scinde Railway Company, and distributed not only at every station on the line, but at most of the important towns in the Indus Valley from Hyderabad to Mooltan. The distance which existed between the rain-gauge stations on the Scinde Line was worthy of remark, showing as it did the extraordinary partiality of the rainfall. In no case was there a distance of more than from 12 miles to 14 miles between these gauges. Between Joongshaie and Dorbajee, where the greatest difference of rainfall existed, the distance was only 19 miles. He believed there was no rainfall whatever at the former station, when the enormous fall of 20 inches in six hours occurred at the latter. The detailed observations were given in the rainfall returns, a copy of which he presented to the Institution. If the Railway Companies in India would take the trouble to establish rain-gauges at each of their stations it would be a great assistance towards obtaining the complete registration of rainfall in that country, which it was so desirable to record and collate. The expense would be small, as the register could be kept, as was the case on the Scinde Railway, by the booking clerk, the telegraph clerk, or the station inspector. He had found the Government of India quite alive to the importance of these records, and most ready to afford facilities for establishing rain-gauges at various points along the Valley of the Indus. At present these registers were kept by the resident medical officers connected with the district hospitals. Such registers were found valuable to the revenue officers of the Government as statistical records, giving them approximate data for calculating the yield of prospective harvests.

There was one observation he would like to make with regard to some facts stated in Mr. Bidder's report. He was always opposed to raising the line of the Scinde Railway at any point; in fact, he had lowered the railway so as to allow the floods to pass over it. In his Paper on the Scinde Railway, read in the year 1862,[1] the fact of his having lowered the line to the surface across the Pipri plain, was received with considerable astonishment. The flood of 1866, so much in excess of any on record, passed harmlessly over this portion of the line; which proved that this was the proper mode of dealing with it in this and similar situations. But this would not answer in the cases mentioned by Mr. Graham, where on an extensive plain the flood water remained for many days and passed off very slowly.

As it might be of interest, he presented a copy of the daily record of the rise and fall of the River Indus during several years.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 451.

This registration was kept by Government officers at Bukkur Island. There was another kept at Kotree, and they formed an important item in the statistics affecting the irrigation of the province of Scinde.

Mr. Henry Law observed that the River Amazon, though it drained a larger district of country than any other river in the world, and in some parts was subject to a rainfall of 280 inches per annum, nevertheless had a very uniform mean height of water, resulting from the fact that the rainy season of its southern tributaries coincided with the dry season of those to the north, and *vice versâ*.

Lieutenant-Colonel J. P. Kennedy thought that all conclusions should be derived from well-ascertained facts rather than theories. He believed that the calculation of rainfall on any given drainage basin might lead to most erroneous inferences, if derived from too limited a number of rain-gauge records, owing to the great difference of rainfall which occurred within very short distances; and at the same time that, if such records could be obtained for all the varying degrees of rainfall, with the relative corresponding areas, nothing could be more conclusive. He divided the periodical floods of India into two classes:—Those affecting inland rivers, and those affecting tidal rivers. In dealing with the latter, he had adopted the highest spring-tide level as the practical bed for the inland flood-waters; above which sufficient sectional area should be left for the outflow of the fresh waters at their recorded maximum, with an ample clearance or headway under the lowest member of every bridge superstructure. He would thus provide for the coincidence of high-water spring-tide with a maximum rainfall, as the contingency regulating the sectional area for outflow. Such were the considerations that had regulated the bridging of the Nerbudda, and about eighty other rivers and estuaries requiring an aggregate of about 6 miles of viaduct on 300 miles of the western coast line of railway in India. (Plate 12.)

He considered that, in fixing the sectional area of a bridge to void the waters of any drainage basin, it was important that no point below the bridge should limit the transverse sectional area under that allowed at the bridge itself, calculating only the space above high-water of spring tide. This and all other impediments to the outflow of floods, with all causes of back-water inundation of flat grounds, called for the remedies of judicious cuts for discharge seawards, and controlling artificial banks at ample sectional distances, and with ample slopes on the river sides where necessary. These were works of so comprehensive a character as to be only within the power of application by the broadest action of Government, and far beyond the functions of those conducting merely local operations.

When fixing the required outflow for bridges, in crossing the

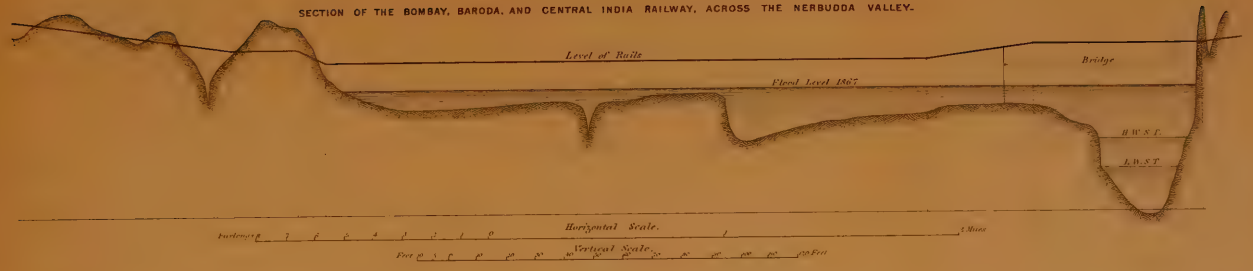
drainage basins now referred to, there were no official records of floods to aid the engineer, whose only resource was such evidence as could be collected from the vague statements of the elders in each district as to the highest floods within their memory. Under these circumstances, in dealing with so many torrential rivers with most variable alluvial beds, he felt that the results obtained had been satisfactory, as the bridge superstructures were proved in practice to be at the right elevation, and not a single failure of foundation had occurred in any of the five hundred pile piers supporting those superstructures; whilst it had been necessary to screw some of the piles to more than 40 feet below the river bed to reach satisfactory foundations—the average depth being about 20 feet, and the average cost of the viaducts about £30 per lineal foot. He stated that by a strange inconsistence in some of the officers charged with the conduct of these operations in India, the abutments of the bridges had not been so successful as the piers, as they had been constructed in masonry or brickwork, and not, as intended, with the screw piles, which were easily sent down to the necessary depth of firm foundation. But all abutments were now erected upon the same principle as the piers; and he believed that the erroneously-constructed abutments yet remaining might have to be replaced by pile abutments, as the scour of the stream reached the shallow foundation. Fortunately, the screw pile principle admitted of such improvements being made without suspending the traffic.

He described the scour produced in the monsoon floods as the never-ceasing enemy to bridge structures and all other works on Indian rivers; and the evil next in degree to scour was that of drift wood, upon which latter subject he had frequently suggested the necessity of strict precautionary supervision by the Government, through the Forest Department, the magistracy, the police, and the collectorates. The simple remedy against drift timber was to oblige all owners of felled trees lying within reach of the monsoon floods in every tributary and principal river to remove them prior to the rains, thus averting the possibility of those battering rams being brought down against the piers, and other structures by the rapid monsoon floods.

Mr. G. J. Symons would look after the registration of the rainfall of the various watersheds in England, if any individual members of the Institution would undertake the work of the outfall registration. He had at the present time information from fifteen hundred gauges scattered all over the country; there were therefore stations already established for determining the amount of water falling on the different catchment basins: the question was whether the outfalls of the country could be gauged in a similar manner. Some astonishment had been expressed at a rainfall of 500 inches

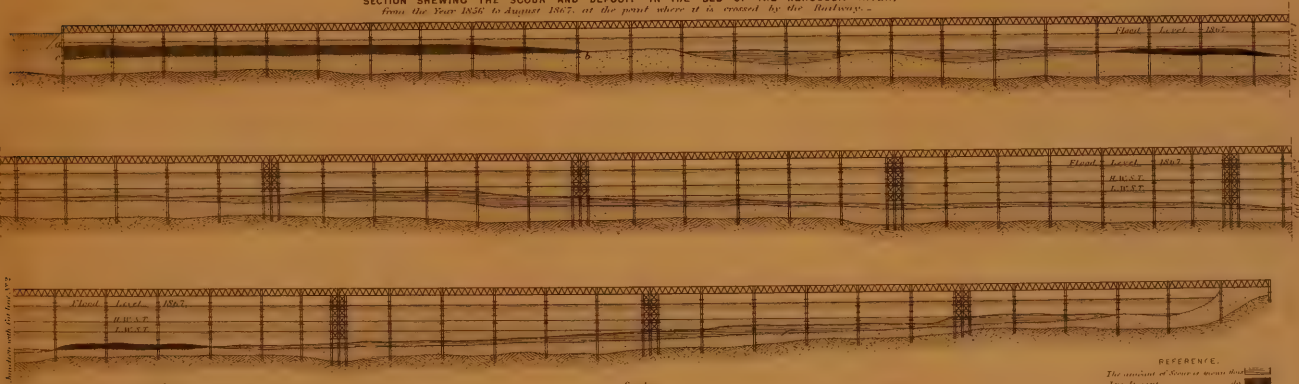
FLOODS IN THE NERBUDDA VALLEY.

SECTION OF THE BOMBAY, BARODA, AND CENTRAL INDIA RAILWAY, ACROSS THE NERBUDDA VALLEY.



SECTION SHEWING THE SCOUR AND DEPOSIT IN THE BED OF THE NERBUDDA RIVER,

from the Year 1856 to August 1867, at the point where it is crossed by the Railway.



NOTE.

It has been proposed to remove a portion of the south bank of the River marked A by dotted lines to the H.W.S.T. line, by flushing the material the rock by other parallel to the direction of the current. But to do so would be to divide additional waterway to meet the occurrence of a maximum flood, formed both spring tides also to protect the piles and abutments and current of water to be sufficient for navigation. Piers to have by large stone ballast on bags of concrete

REFERENCE.

The amount of Scour is shewn thus

The Deposit thus

W. P. KENNEDY, LITHO. 36, PALL MALL.

ALLEN BROTHERS & CO. LITH. 23, HOLBORN.

in India; but that was by no means uncommon. Even in this country considerably over 100 inches had been regularly recorded year by year, and as much as 225 inches was measured in 1866 at the Stye, Borrowdale, Cumberland.

There was a remark in the first Paper that the rain decreased in quantity from the equator to the poles. That dictum was laid down by Humboldt; and though true to a certain extent, it was not rigidly so, inasmuch as in the north-west of North America there was an average fall of 80 inches, whereas at Kurrachee it only amounted to about 3 inches, showing the reverse of that generalization. To ascertain the maximum fall of rain in a minimum time he had designed a rain-gauge on a scale which admitted of its register being read at a distance of 50 feet or 60 feet, without having to go out of doors for the purpose. By this gauge the rate of fall minute by minute could be readily observed. The mean rainfall was to a certain extent a guide as to the maximum daily fall: a result he had arrived at within the last year and a half. Although there occurred in Cumberland a fall of 6 inches in twenty-four hours, yet the largest percentage of annual fall was not in that district, but in the Midland Counties; if the mean there was taken as 20 inches, a maximum fall of about 16 per cent. out of the 20 inches, or from 3 inches to 3½ inches might be expected, and provision should be made accordingly; but that percentage ran down 0·25 per cent. for each increment of an inch of mean fall till a mean annual fall of 60 inches was attained, at and above which the percentage appeared to be uniformly about 5 or 6 per cent. Thus, the mean rainfall at Seathwaite was 140 inches; 5 per cent. thereof was equal to 7 inches, against 6·62 inches the maximum observed in twenty-four years. This gave a maximum fall of only 3½ inches for ordinarily wet stations; which was less than occurred at the dry stations, with 20 inches per annum for their mean fall. With reference to the influence of vegetation upon the rainfall of districts he might state that, under the direction of the authorities of Kew Gardens, some trees not requiring much moisture were planted on the Island of Ascension, which was formerly described as a cinder-heap, and since that time the rainfall had increased. In conclusion he remarked that if the various Railway Companies would adopt the plan of gauging which had been undertaken by the canal department of the Manchester, Sheffield, and Lincolnshire Railway Company, it would place those interested in this subject in the possession of very valuable facts.

Mr. J. M. Heppel, in replying upon the discussion in the absence of Colonel O'Connell, observed that when rain fell on any solid surface and then drained off, it formed a drainage vehicle. It had been pointed out, very justly, that after such drainage vehicle had been formed, the discharge, in the case where the rainfall was constant,

must be directly proportional to the area; that was to say, after the discharge of water in the basin had acquired some such condition as was called a train in a river or canal. This law had been pointed out as the limit to which the discharges approached when the areas were small; and he thought it was evident that they would approach the limit in that case, and that the larger the areas became, the wider would be their departure from it: because, though in the case of rainfall continuing over a long space of time no doubt the discharge would be simply proportional to the area, still it did not follow that in a variable rainfall, increasing from a minimum to a maximum, the discharge would be proportional to the maximum. He was glad to hear that, in the opinion of Professor Austed, the treatment proposed was a step in the right direction; and he fully concurred in that opinion. One of the first of these disturbing circumstances, to which the Author had given the appropriate name of moderators, was represented to be the extent of the drainage area; and the way in which this was treated in the Paper, after some relation between the discharge and the area, was by the introduction of an index different from a unit: which he considered not an unreasonable way of proceeding. In the course of the discussion a different index, 3 by 4, had been proposed, and likewise one 2 by 3, which was nearly a mean between the other two, as the Author proposed the index $\frac{1}{2}$, or the square root of the area, which was graphically represented by the common parabola. It appeared that Colonel O'Connell wished an accurate register to be made of *bonâ fide* observations, and that then trial curves should be taken from them, to see how nearly they corresponded with the common parabola. These lines produced a kind of classification, and the parameter that distinguished one of them from another the Author called the modulus. If no relation could be found amongst those moduli, there was no good done by constructing the curves: but if it was found that one shot through one class of rivers and another through another, and that these classes offered distinctions capable of recognition, then, he thought, a step in advance had been made. It was evident that if the modulus, which was the quotient obtained by dividing the square root of the area by the discharge, afterwards appeared to be any function of other quantities which might be expressed quantitatively and introduced into the formula, then some progress would have been made. He thought there were many formulæ in the position of that which had been now proposed, of which one instance was afforded by Dubuat's formula, constructed fifty years previously, where he began by investigating whether the resistance of the flow of water in channels was not proportional to the square of its velocity. That was a legitimate supposition to begin with. He found it was not as the square of the velocity; but the results

being compared, it was ascertained that the residual quantity bore a distinct relation to another element, which was the hydraulic mean depth; and it was the means of discovering that valuable function in hydraulics. Supposing Dubuat had not discovered this second function, there might have been some reason for saying, that data had been submitted which had no discernible relation to each other: but that had not been the case. In reference to the methods adopted in passing the great floods of the River Indus, as far as he had ascertained the character of the valley, nothing could have been more efficient for accomplishing the purpose: at the same time he thought the case was exceptional, as from his own experience of a long line of railway in India, he could not call to mind one place where such a method of passing floods would have been desirable or even possible; and he thought, from the observations of Mr. Graham a similar difficulty would have been experienced in the case of the Great Indian Peninsula Railway.

Mr. Robert Manning observed, through the Secretary, that the foundations of all useful knowledge on the subject of Colonel O'Connell's Paper must be laid on accumulated observations of particular cases.

There was no doubt that difficulty would be found in selecting data from which proper values might be obtained for the various circumstances which influenced the maximum discharge; he would therefore suggest the following:—

First, the maximum daily rainfall.

Secondly, the area of the rain-basin.

Thirdly, the average elevation of the watershed above the main outlet.

Fourthly, the extent of lake surface.

Fifthly, the distance of the centre of magnitude of the rain-basin, measured along the river, from the main outlet.

Sixthly, the maximum discharge.

He had collected more than eighty cases, a mere arrangement of which, in the order of the areas of their basins, roughly indicated the general law under the influence of which sudden floods were known almost entirely to disappear in large rivers. With such data as he had named, it would not be difficult, although troublesome, to obtain a general expression for the maximum discharge, so far at least as the data were compatible with each other. Any formula thus obtained should, in his judgment, be a concise expression of the facts collected, and nothing more.

In the cases to which he had alluded—all of which were in Ireland—the maximum discharge varied from 10 cubic feet to 250 cubic feet per second off each 1,000 acres; such a wide range gave ample scope for investigation, without entering into any theoretical refinements, particularly as the effects of absorption and

evaporation, so necessary to be considered in the calculation of the minimum and mean discharges, could have little influence on the maximum, as was evident from the fact, often and independently observed, that for two, or even three months in the year, the entire rainfall was discharged.

There could not be any doubt that the collection, arrangement, and discussion of facts connected with the discharge of rivers, under different circumstances of elevation, area, and rainfall, were of the greatest importance to hydraulic Engineers, and any one who undertook the task, and pointed out, by formula or otherwise, any general law by which the discharge was influenced, placed the entire profession under an obligation to him, and did good service to practical science.

Mr. Francis Fowler communicated, through the Secretary, some remarkable facts which he observed during a residence of several years in India, especially in the great valleys of Scinde and the Punjaub. These valleys covered an area of 300,000 square miles, and to the eye had the appearance of a dead flat; but in reality there was a gradual fall from the Himalayan Mountains to the sea, of about 2 feet in the mile, following the general course of the five great rivers of the Punjaub, and, in its lower parts, the valley of the River Indus, into which the former all converged.

Throughout this vast tract of country, on careful levels being taken, slight inequalities of surface, not sensible to the unassisted eye, were brought to light; these irregularities seldom exceeded a few feet in vertical height; so much was this the case that on the whole length of the Punjaub Railway—above 250 miles—there was not a single cutting, the whole line being raised above the general level of the country, on an embankment averaging not more than 3 feet or 4 feet in height.

Whilst engaged, as an Assistant Engineer, in running the preliminary lines for this railway, in the cold season of 1856-57, it was the object of the Engineers to find the highest tract of country, so as to be as much as possible out of the influence of floods, and many lines were run for that purpose – amongst others, a trial line through a district which had been avoided, as on the map was marked the old bed of the River Beas, one of the five rivers of the Punjaub, consequently it was supposed that this must be a low tract of country; but the results of the trial sections showed that it was the highest line run, and the railway was constructed upon that line.

During the next cold season, in levelling from Sukkur, on the River Indus, towards the entrance of the Bholan-Pass, in the Himalayan Mountains, he was surprised to find that, on leaving the banks of the Indus and approaching the mountains, the country became lower the further the distance from the river, thus showing that that

immense river was running through the highest portion of the neighbouring country, in the same manner as was proved with the old bed of the River Beas in the Punjaub. This at first sight appeared to be a paradox, as it was generally considered an axiom in engineering that a country rose towards a mountain, and fell towards a river; but in this case it was precisely the reverse; and the general level of the country at Shikarpore, a distance of upwards of 20 miles from the river, and by so much nearer the mountains, was lower than its banks.

Afterwards the line of levels was continued onwards to Jacobabad, parallel to the military road constructed for about 50 miles by the Indian Government. This was altogether on an embankment, generally a few feet in height. There were some rather extensive viaducts as flood openings; one of them of fourteen spans of 30 feet, and several others respectively of eleven, nine, and seven spans of the same width. These were all built in brickwork; but under most of them no water ran, but through taking a fresh course created great havoc on the banks in distant places.

Water, as was well known, always pursued the easiest course, although this might not always be the lowest, as the above instances proved; in fact it often flowed on a self-raised bed. As flood waters invariably brought down with them from higher regions more or less of a sediment, the result was that, in a flat country, the rivers overflowed their beds and spread for many miles on each side over the adjacent country. Every flood brought with it fresh sediment which, when the water fell back into its accustomed channel, was left behind; this occurring year by year through many ages, resulted in raising the whole bed of the river and its banks above the neighbouring country, till at length the river ran along a ridge many miles in breadth, and continued to do so until some extraordinary flood took place. This must have been the case with the River Beas above mentioned, and the water cut a fresh channel, rushed into the lower parts of the country, and never returned, but commenced anew to raise the low tract to the level of the higher, and, in course of time, to a still greater height than its former bed; this, he considered, explained the gradual but vast geological changes in alluvial countries, which had occurred in so many places on the face of the earth.

To return to the road and the forsaken bridges; the engineer had hastily brought about what Nature would have done in its own good time. Throughout the Punjaub and Scinde, and no doubt in other parts of India, there were certain tracts of country over which, during the rains, a thin sheet of water only a few inches deep, sometimes miles in width, gradually moved onwards with an almost imperceptible flow, and, if left alone, did no damage, and, as had been found in the lapse of centuries, raised the tract

over which they moved considerably above the neighbouring country. This went on until the engineer arrived, who by making up a bank, and building a bridge where water was running, created an obstacle by the piers and approaches, and raised the sheet of water in a small degree; the water then ran off the table-land, rushed down into lower districts of country, never again approached the bridges, but dashed through the banks miles away from where it ever ran before, and created tremendous havoc; and the bridge stood a lasting monument of the manner in which water refused to be treated otherwise than on the true principles of Nature.

These remarks only applied to floods in low, flat districts of country, and had no reference to river torrents, or to hilly or undulating countries. He could speak from experience how continually these effects were overlooked, as he had in many cases seen bridges and culverts marked on sections at points with lower ground in the neighbourhood, and placed there simply because they were the points where the water always did run, but where, after the road or railway was completed, it would never run again. He was confident these facts had never been sufficiently borne in mind, either by the Government or by railway Engineers, in designing works in India, or there would not be annually after the rains such sad reports of the destruction of banks on so large a scale in that country, not only causing a large expenditure of money in repairs, but disjointing the whole system of internal communication in that fertile region, where was exemplified, more than in any other country, the old adage of how good a servant, but bad a master, water was and ever would be.

Mr. A. A. West observed, through the Secretary, that in July, 1853, several of the rivers in the Satara Districts of the Bombay Presidency, which had their sources in the Ghauts of Western India, were flooded to a higher level than had been previously known. On the 12th of that month, one of these rivers—the Krishna—at a point 37 miles from its source, rose 12 feet above its highest previously known level. From measurements of this unusual flood, the discharge was found to be about 118,000 cubic feet per second, from an area of 345 square miles. This gave an average of 342 cubic feet per square mile per second; equivalent to a rainfall at the rate of 0·53 inch an hour, or about 12·7 inches in twenty-four hours.

The local character of heavy falls of rain was illustrated by one of the smaller rivers at the same time. Its source was close to that of the Krishna, and it ran down a parallel valley, but it attained its maximum, 6 feet higher than any previously known, three days earlier than the Krishna, and when the Krishna was at its highest, was at an ordinary flood level. Upon the same occasion, the united streams of the Krishna and the Koyna, at the

town of Kurar, about 82 miles below the source of the former river, rose 10 feet above the highest traditional level, a height not attained since, the flood of the year 1853 being the maximum down to the present time.

Mr. A. H. Vaux observed, through the Secretary, that the importance of possessing a useful means by which to classify rivers was especially apparent in Bengal in 1866 when, at the beginning of July, a remarkable flood occurred in Beerbhoom, causing much damage to the country, and temporarily obstructing the traffic of the East Indian Railway, by injuring its under works. While assisting the chief Engineer, Mr. Samuel Power, M. Inst. C. E., in preparing a report to the Directors, he endeavoured to classify the different rivers which the East Indian Railway crossed, and for which the sufficiency of the waterway given was doubted. These were all the southern tributary streams of the River Ganges, between Allahabad and Calcutta, 600 miles. Great difficulties were encountered in the attempt, as in any classification it was necessary to ascertain the area drained, the mean and exceptional amount of rainfall, and the quantity of water carried off by each river; and no certain information could be obtained on any of these points. The drainage basin could not be accurately defined, because not only did the watershed on the surface differ from the line of watershed geologically considered, but the flood itself caused grave changes in the direction of the rivers. Dams constructed for irrigation purposes were, in some instances, swept away; again, masses of trees or the débris of villages were arrested in their downward progress, and caused natural dams sufficient to divert the rivers into channels differing from those in which they formerly ran, and even occasionally throwing the whole body of a second river into the channel of one which appeared to have a totally distinct drainage basin. It was thus impossible to say at what point rain, which fell on certain hills, flowed into the main Ganges. The difficulty of obtaining accurate registers of the amount of rainfall daily over even a small area must have struck most engineers, and of course, in the case in question, where the rivers drained areas varying from 20 square miles to 20,000 square miles, the difficulty was greatly enhanced. A gauge situated at Soorey, at the foot of some wooded hills, registered, according to the observation of the civil surgeon of the station, 50 inches of rain in forty-eight hours; but probably rain fell more heavily in other adjacent places, where the mean fall might not perhaps exceed 70 inches in the year. Though the areas drained and the amount of rainfall were thus undefined, the Resident Engineers endeavoured to ascertain the quantity of water which passed the railway. Here again they were baffled; they knew accurately the width of opening of the bridges, but in spite of the vast volume

of water surging round them, they were able to approximate to the surface velocity at which the water passed, and they were quite unable to measure the depth of the flood. In the dry weather the rivers were rivulets flowing over fine sand. This was disturbed as the flood rose, and the beds of the rivers were quickly torn away to an uncertain depth, by a torrent running 10 miles an hour. No soundings could be taken while these violent floods continued, and when the velocity moderated the bottom of the river was found to be again silted up. As a simple instance of a river difficult to gauge, mention might be made of the Keeul, which drained a definite basin of 1,100 square miles of hilly land, was not liable to inundate its margin, and flowed through a well-marked channel, until it reached the East Indian Railway, which crossed it by nine spans, each 150 feet; the piers being founded on wells sunk through deep sand. Here the water came down suddenly, and while the fresh lasted, the depths could not be measured.

It was to be hoped that Engineers who had had opportunities of observing "the relation of fresh-water floods of rivers to the physical features of their basins" would take this opportunity, for the sake of their brethren who practised in countries but little known, to record their experience as to the effect which flowing water of different depths and speeds had upon different subjacent soils. Published experiments appeared invariably to give too high a value to the power of flowing water to move sand and light clay. Rivers flowed at fair speed through countries formed of the lightest alluvial soil, and yet varied their course but slightly. A speed of 2 and 3 feet per second did not seem to be a destructive rate over light clay.

Mr. Power's report on the special flood referred to, and on the subject of the floods of the southern tributaries of the Ganges, was as follows :—

"From S. Power, Esq., Chief Engineer, East Indian Railway Company, to the Chairman of the Board of Agency, East Indian Railway Company, 28th August, 1866.

"Sir,

"My letter of 7th July described the failure of the Buckasore, Copai, and Bheddiah Bridges on the 1st July, and the consequent stoppage of the traffic, also the temporary remedial measures which were at once adopted, and by means of which the passenger traffic was re-opened on the 10th July and the goods traffic a few days later.

"In compliance with the wishes of the Government of India, the accompanying drawing and the reports of Messrs. Cockburn and Latimer are now submitted. They exhibit and describe in detail the structure of these bridges and the injuries which they have sustained; the measures which have been extensively adopted with success for the purpose of permanently protecting the bridges of the East Indian Railway from the destructive action of the floods, and those which have been tried in a few cases and have failed; and also the proposed improvements.

"There is also appended a tabular statement which shows the areas of the basins drained by the great rivers and their tributaries which are crossed by this railway: the waterway afforded by the existing bridges, and the velocity with which the water must have passed through them, assuming that they have during recorded floods discharged a rainfall of half an inch per hour; this being half the quantity which was ascertained by Mr. Levinge's careful experiment to have fallen in the basin of the Gerooah during the great flood of 1861; no other trustworthy record of the rainfall has been kept by the railway officers.

"The cause of the failure of the bridges must now be considered.

"It might have been a defect in construction or in design, a deficiency of waterway, or insufficient depth of foundation.

"It did not arise from any defect of construction, because both workmanship and materials are indisputably excellent; nor from a faulty design, because the general plan is perfect of its kind, and one which has been almost universally adopted with success.

"It must therefore have arisen from a deficiency of the waterway or from the insufficient depth of the foundations.

"A sufficiency of waterway is generally supposed to include the following conditions:—

"1st. That the floods shall not rise above the embankments.

"2nd. That the extent of inundated land shall not be injuriously increased.

"3rd. That the velocity of the water passing through the bridges shall not be so great as to scour away the clay or other material on which their foundations rest.

"If this definition be assumed to be correct, it must at once be admitted that the failure was caused by the non-fulfilment of the third condition, because the clay was certainly scoured from beneath the piers, which settled or fell when the ground on which they rested was carried away; and, moreover, it is shown by the annexed tabular statement, that the velocity of the water from a rainfall of ½ an inch must necessarily have been such as to produce this effect, being nearly five times that which most recent and careful observations show to be the safe velocity, viz., 2½ feet; and, finally, it is shown by the levels since taken by Mr. Latimer, that the head of water exceeded 5 feet, which must have produced a velocity of 16 feet per second.

"It is scarcely necessary to point out that this investigation entirely confirms the truth of Mr. Turnbull's opinion, that the waterway was insufficient, and that every addition to it must have increased the chances of safety.

"But the inquiry also proves that a moderate addition to the bridges will not alone suffice to insure their safety; and that, although for several reasons a large addition to the waterway will, in particular places, be advisable, the chief remedy for the dangerous condition of the bridges must be sought not in this extension alone, but in rendering them, as nearly as practicable, safe from the effects of the most violent scour.

"4th. The insufficient depth of the foundations is another cause which has to be considered.

"The surface of the clay, which underlies the sand or silt in the beds of these rivers, appears to have been assumed to be the limit of the scour, because the latter (viz., the sand or silt) was probably deposited by one flood and liable to be removed by another, while the surface of the clay had not been disturbed, and therefore marked with certainty the limit below which the scour of the rivers had not formerly extended. But any departure from the normal condition of the drainage must alter this limit; and when the railway bank was constructed, and all the rainfall was forced

to pass through the bridges instead of flowing over the ground, the surface of the clay ceased to be the limit of the scour or the safe depth of foundations.

"It would of course be possible to calculate approximately the additional depth to which the foundations should be sunk, *i. e.*, that to which the river channels must be deepened, in order that they may be enabled to carry with a given velocity the additional water forced through them by dams across the valleys; but, as sinking blocks into the clay was almost impracticable with the implements formerly in use, it is useless to enter further into this matter. The best remedies for the existing evils form a far more important subject of consideration, and they must now be discussed.

"In consequence of the excessive quantity of water which has to be discharged through most bridges on this railway, their position has become somewhat similar to that of canal locks, and the means which have always been found adequate for the security of the latter will certainly be found efficacious in protecting the former: these means are a flooring which cannot be injured by any possible velocity with which the water can move over it, and the prevention of the passage of water under the flooring or behind the walls of the lock chamber or sluices by means of sheet piling, or their more permanent, but less effective substitute, dropwalls, sunk to a sufficient depth in the clay.

"In bridges having inverts resting on the clay, this method of protection (viz., a solid flooring and dropwall) has been easily applied and has been perfectly successful, except in the case of a small bridge at the 109th mile, where the dropwalls were sunk only 4 feet. But, although thus far successful, it exhibits defects, which require attention;—they are the insufficient width of the aprons, the insufficient depth of the dropwalls, and the want of adequate protection behind the wingwalls and abutments. In reference to the first it was frequently observed that the eddies by which the foundations of the bridges are generally damaged have been usually produced close to the upper faces of the bridges. Major Hovenden and I had an opportunity of seeing that the sod, covering the surface of the ground, had not been disturbed at a distance of 10 feet from the face of the Bheddiah Bridge of three 15-feet arches, which was nevertheless so completely undermined that it dropped into a hole scoured under its bottom. On account of the narrow limit within which the scour thus appeared to have been confined, the aprons have hitherto been made only 15 feet wide. No mischief has as yet been caused by this limit—no invert bridge protected in the manner shown in the drawing having been damaged; it was, however, I now think, injudicious economy on my part, and the aprons should extend to the foot of the slope, and the dropwalls should be sunk to a greater depth (10 feet) where practicable. Moreover, the wingwalls have not in all cases been underpinned to the same depth as the dropwalls: this should now be done in every case, and the bank behind the wingwalls and for some distance beyond them should be covered with a solid pavement.[1]

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[1] It should be understood that this letter was not written with a view to publication, but merely for the purpose of satisfying Government as to the necessity for the immediate consideration of additional works which had been recommended by Mr. Turnbull and Mr. Power, and generally approved by Government, but which it had been hoped might have been deferred. The letter should on the whole be viewed as a contribution approximating (as nearly as circumstances permitted) to accuracy, and suggesting future inquiry.

The accurate adjustment of water-way on Indian railways was a difficult problem, for many reasons; such as the difficulty of obtaining trustworthy informa-

EAST INDIAN RAILWAY.

COMPARATIVE STATEMENT of WATERWAY on the several Districts of the Main Line in the Bengal Division.

NAMES OF RIVERS.	Area of Basin to be drained.	Waterway given in the Railway Embankment.		Area of Waterway below recorded Flood-level per Square Mile.	Estimated Amount of Rainfall to be carried off through the Railway Vertical Inches per Hour.	Quantity of Water to be discharged per Square Foot of Waterway per Second to carry off this estimated Rainfall.	Mean Velocity at which Water must have passed through the Railway Openings if this estimated Rainfall has been carried off.	Estimated addition to existing Waterway required to reduce this velocity through Bridges below 2½ feet per second, existing Waterway being 1.	Remarks.
		Lineal Feet.	Square Feet below recorded Flood-level.						
	Sq. Miles.			Sq. ft.		Cubic Feet.	Lineal Feet per Second.		
1. Kurrumnassa	3,400	4,000	39,000	11	·25	162	15	5	The rainfall over these districts is comparatively light.
2. Soane River	23,000	14,200	172,500	8	·125	81	10	3	
3. Poon-poon and Hullohur Valleys	9,000	11,086	123,648	14	·25	162	11	3	
4. Keeul River	1,100	1,542	11,092	10	·25	162	16	5	
5. Hill Streams west of Jamalpore	240	1,670	7,385	30	·5	323	10	3	
6. Hill Streams from Jamalpore to Sahebgunge	2,650	6,796	59,486	23	·5	323	14	4	The rainfall over this country is much heavier than in the districts west of Monghyr.
7. Hill Streams from Sahebgunge to Teenpahar	52	1,641	7,952	155	·5	323	2	..	
8. Hill Streams from Teenpahar to Bahawa	66	1,176	2,476	144	·5	323	2	..	
9. Gomanee River	520	1,639	10,165	20	·5	323	16	5	
10. Hill Streams between Gomanee River and Mullarpore	1,200	5,824	53,301	44	·5	323	7	2	
11. Adjai and More Valleys	3,640	7,752	120,300	30	·5	323	10	3	
12. Khanoo to Howrah	*	14,000	55,000	..	..	..	..	..	

* The drainage area is uncertain, owing to the River Damooda being embanked and liable to overflow.

NOTE 1.—Much doubt exists as to the effect of running water on different substances.

It was formerly supposed that a velocity of 6 inches per second moved ordinary clay. Mr. Blackwell's experiments in 1857 appeared to show that a velocity of 2½ per second would move a brickbat weighing 9 oz.

Major Crofton, however, considers 2½ feet to be a safe velocity on clay, and it has been adopted in this statement lest the table should appear exaggerated.

NOTE 2.—No attempt has been made to divide the drainage of the great basins and to show the discharge of each tributary separately, because the inosculation of many of the rivers renders a correct division impossible. The Kandour, one of the southern tributaries of the Adjai, may be taken as an example of this difficulty; the Adjai burst its south bank, filled the valley of the Kandour, topped the railway bank, and swept away the Bheddiah Bridge. Colonel Short, whose authority cannot be questioned, informs me that this irruption of the Adjai took place on the 1st and 2nd July.

28th August, 1866.

(Signed) S. POWER, *Chief Engineer.*

Mr. J. B. Redman suggested, that the following remarkable letter, extracted from the "Times" newspaper of July 23rd, 1856, should be appended, inasmuch as it referred specially to the subject under discussion :—

"The Emperor of the French has addressed the following letter to M. Rouher, the Minister of Public Works :—

"' Monsieur le Ministre,—

"' After having examined with you the ravages caused by the inundations, my first object of consideration has been to find the means for preventing similar disasters. According to what I saw, there are in the greatest number of the localities secondary works, indicated by the nature of the ground, and which skilful engineers might readily execute. Thus, nothing can be more easy than to construct works of art which would temporarily preserve from such inundations cities such as Lyons, Valence, Avignon, Tarascon, Orleans, Blois, and Tours. But as to a general system to be adopted in order to protect for the future from such terrible scourges our rich valleys traversed by large rivers, that is still wanting, and must be absolutely and immediately found.

"' At the present time every one calls for a dyke, being satisfied with diverting the water from himself and throwing it on his neighbour. The system of dykes is only a palliative, ruinous for the State, and imperfect for the interests to be protected : for, in general, the sand which is brought down constantly elevating the bed of the rivers, and the dykes tending to narrow them, it is necessary to be constantly adding to the height of those dykes, to be prolonging them along both banks, and to subject them to a constant superintendence. This system, which, for the Rhone alone, would cost more than 100,000,000f., would be insufficient, for it would be impossible to obtain that uninterrupted surveillance along the whole extent of the banks which could alone prevent a rupture; and, should one dyke break, the catastrophe would be the more terrible, as the dykes would have been raised higher. In the midst of all the systems proposed one alone appears to me to be reasonable, practicable, of ready execution, and which, moreover, has experience in favour of it.

"' Before seeking the remedy for an evil it is necessary to study well its cause. Whence, therefore, proceed these sudden risings of our large rivers? They are caused by the rain which falls on the mountains, and but slightly by that which falls on the plains. This is evident from the fact of the rise of the Loire having been felt at Roanne and at Nevers twenty or thirty hours before it reached Orleans or Blois. It was the same with the Saone, the Rhone, and the Gironde; and during the late inundations the electric tele-

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tion respecting floods, the absence of observations of rainfall, and the necessity for speedy construction, compelling the adoption of conclusions from imperfect data. That the water-way of the East Indian Railway was originally adjusted with a remarkably close approximation to accuracy might be inferred from the fact, that on a line more than 1,300 miles in length, and having nearly 30 miles of bridging, only four small bridges had been seriously damaged by the floods, and that the traffic had only been interrupted during a few days. On the "chord" line, now under construction, a space of 100 superficial feet of sectional area of water-way was allowed for every square mile of area drained ; this would discharge a depth of 1 inch of rain per hour, which was known to occur there, at the rate of 4 miles per hour—certainly a safe speed through bridges protected as these would be by aprons and dropwalls 6 feet in depth.—S. Power.

graph served to announce to the people, several hours, or rather several days, beforehand, the precise moment of the rising of the waters.

" ' This phenomenon may be readily understood. When the rain falls on a plain the ground serves as a kind of sponge, and the water, before reaching the river, has to traverse a vast extent of soft ground, the gentle slope of which also retards the running off of the water. But when, independently of the melting of the snow, the same thing takes place on the mountains, where the ground, mostly rocky or gravelly, does not absorb the moisture, the steepness of the country carries the water rapidly to the rivers, which thus suddenly rise. This is what we see every day when it rains. The rain which falls in our fields seldom forms a stream, but that which falls on the roofs of houses, and which runs into the gutters, instantly does so. Thus the roofs are the mountains, and the gutters the valleys. If we, therefore, suppose a valley four leagues long by two wide, and that there has fallen in the twenty-four hours 10c. of rain on that surface, we shall have in the same space of time 12,800,000 cubic mètres of water, which will have run into the river; and this phenomenon will be renewed for each of the tributary streams of that river. Suppose, therefore, that the Rhone or the Loire has ten large tributary streams, we shall have the immense volume of 128,000,000 cubic mètres of water, which will have run into the river in twenty-four hours; but if that volume of water can be kept back in such a manner that its running off must occupy twice or thrice the space of time, then, as may be readily conceived, the inundation will be rendered twice or thrice less dangerous.

" ' Everything, therefore, consists in retarding the running off of the water. The means of effecting this is to erect on all the tributary streams of rivers, at the mouths of the valleys, weirs, leaving in the centre only a narrow passage for the waters, and thus keeping them back when their volume increases, and forming reservoirs which could only empty themselves slowly. It is necessary to do on a small scale what Nature has done on a large one. If the Lake of Constance and the Lake of Geneva did not exist, the valley of the Rhine and that of the Rhone would only form two vast sheets of water; for every year the above-mentioned lakes, without any extraordinary fall of rain, and merely from the melting of the snow, rise from 2 to 3 mètres, which makes for the Lake of Constance an increase of about 2½ milliards of cubic mètres of water, and for that of Geneva an augmentation of 1,770,000,000. It may be conceived that with this immense volume of water, if it were not kept back by the mountains which at the opening of those two lakes check it, and only allow it to run off according to the breadth and depth of the river, a frightful inundation would take place every year. This natural inundation was followed, more than one hundred and fifty years ago, by erecting in the Loire a weir, the utility of which is shown by the report made to the Chamber in 1847 by M. Colignon, then deputy of the Meurthe, and which is as follows:—

" The dyke of Pinay, constructed in 1711, is about seven miles above Roanne. This work, resting on the rocks which close in the valley, and enveloping the remains of an old bridge, which, according to tradition, was built by the Romans, reduces the opening of the river at this point to a width of 20 mètres; its height above the ordinary level is also 20 mètres, and it is through this kind of sluice that the whole Loire is compelled to pass at the time of the greatest inundation. The influence of the dyke of Pinay is the more worthy of attention that it was erected, as shown by the decree of the Council of June 23, 1711, for the special object of moderating the rise of the waters, and opposing to their sudden irruption an artificial obstacle in the place of the natural ones, which had been imprudently destroyed in the upper part of the river. The dyke of Pinay well performed its purpose in the month of October last: it supported the waters to a

height of 21m. 47c. above the ordinary level. It thus checked and drove back into the plain of Forez a mass of water estimated at more than 100 millions of cubic mètres; and the rise had attained its maximum height at Roanne four or five hours before this immense reservoir was completely filled. If the dyke of Pinay had not existed, not only would the rise of the water have sooner reached Roanne, but the volume of water would have increased by about 2,500 cubic mètres per second; the duration of the inundation would have been shorter, but the imagination is startled at the addition which might have been made to the disaster, already so great, of which the valley of the Loire has been the theatre. Moreover the rise of the water above the dyke of Pinay produced no injury; far from that, the plain of Forez will for many years feel the fecundating action of the mud which the waters deposited in it. Such has been the part performed by this work, which a wise foresight raised for our security, and to serve us as an example. There exist in the gorges from whence the tributary streams of our rivers flow, a great number of points where the experience of Pinay may be economically renewed, if the localities be well selected, thus usefully checking the flowing of the waters, and in most cases affording a material advantage to agriculture. In place of these completely open dykes, it has been proposed to also construct locks with floodgates. The reservoirs thus formed would keep back the water in times of inundation, and would allow in dry seasons of its being devoted to the wants of agriculture."

" 'The edict of 1711, spoken of by M. Collignon, clearly indicates the part which the dykes are called on to play. It contains the following passage:—

" It is indispensably necessary to make three dykes in the interval of the bed of the river where boats do not pass—the first, at the piles of Pinay; the second, at the Château de la Roche: and the third at the piers of an old bridge built on the Loire near the village of St. Maurice; and, with the assistance of these dykes, the passages being narrowed, the water which would otherwise pass in two days would scarcely be able to do so in four or five. The volume of water, being thus diminished by more than one-half, will no longer cause such ravages as those which have occurred during the last three years."

" 'In fact, in 1856, as in 1846, the dykes of Pinay and La Roche saved Roanne from a complete disaster. It may be moreover remarked, that, according to M. Boulangé, ex-engineer-in-chief of the department of the Loire, the dyke of Pinay only cost 170,000f., and that of La Roche 40,000f., and he estimates the expense at 3,400,000f. for building five additional large dykes and twenty-four weirs, which he proposes to have constructed on the tributary streams of the Loire. M. Polonceau, ex-divisonal inspector of the Ponts et Chaussées, who in part admits the utility of the same system, thinks that these dykes might be formed of turf, or planks, which would be still more economical.

" 'Now, as it is very important that the rise of each tributary stream should not reach the principal river at the same time, it might perhaps be possible, by multiplying the number of those weirs in some places, and restricting them in others, to check the course of certain streams, so that the increased quantities of their water should always reach the main river one after the other. From the example of Pinay, these weirs, instead of injuring agriculture, will be favourable to it by the deposit of mud which will be formed in the artificial lakes, and which will serve to fertilize the ground.

" 'Where rivers bring down sand, these weirs would have the advantage of keeping back a great part of it, and, by increasing the current in the middle of the rivers, make the channel deeper. But even should these weirs do some injury to the crops in the valleys, all that would be neces-

sary to be done would be to indemnify the proprietors: for the same must be done with regard to water as with fire—one part must be sacrificed to save the other; the narrow, but not very fertile valleys must be sacrificed for the safety of the rich land of the fertile plains.

"'The system cannot be efficacious unless it be generalized; that is to say, applied to the smallest tributary streams. It will not be very expensive, if the small weirs be multiplied, instead of very large ones being erected; but it is clear that this will not prevent the necessity of secondary works for the protection of the towns and certain more exposed plains.

"'I wish you, therefore, to have this system examined on the spot, as soon as possible, by the competent men of your ministry. I wish that, independently of the dykes which are to be erected on the most threatened points, there should be made at Lyons a channel for carrying off the great bulk of water, similar to that at Blois; it would have the advantage of preserving the city, and increasing the defence of that fortified place.

"'I wish that there should be made in the bed of the Loire, at a time when the water is low, and parallel to the course of the river, dykes formed of branches of trees open at the upper part, in order to form basins for the mud, as proposed by M. Fortin, engineer of the Ponts et Chaussées. These dykes would have the advantage of stopping the sand without checking the water, and thus deepening the bed of the river.

"'I wish that the system proposed for the Rhone by M. Vallé, Inspector-general des Ponts et Chaussées, should be seriously examined, with the concurrence of the Swiss Government. It consists in lowering the waters of the Rhone at the place where it runs from the Lake of Geneva, and of constructing a weir there. By this means there would be obtained, according to his account, a lowering of the waters of the Leman, which would be useful to the Valais, the Canton de Vaud, and Savoy; and also a better navigation of the lake, embellishments for Geneva, less disastrous inundations in the valley of the Rhone, and a better navigation of that river.

"'Lastly, I wish that, as already exists for some, the management of the great rivers should be confided to one person, in order that the direction may be unique and prompt in the moment of danger. I wish that the engineers who have acquired long experience in matters connected with rivers should be advanced on the spot, and not suddenly taken from their particular works; for it frequently happens that an engineer who has devoted a part of his life either to the study of maritime works on the sea-coast or to hydraulic works in the interior is suddenly, by being promoted, employed on another service, and the State loses the advantage of his special knowledge and the result of his long practical experience.

"'What happened after the great inundation of 1846 should serve as a lesson for us. Much was said on the subject in the Chambers, and very luminous reports were made; but no system was adopted, no clearly defined impulse given. Partial works only were executed; which, according to the opinion of scientific men, only tended, in consequence of their want of *ensemble*, to render the effects of the last scourge more disastrous.

"'I pray God, Monsieur le Ministre, to have you in his holy keeping.

'"NAPOLEON.

"'*Plombières, July* 19.'"

February 11, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the two Papers, Nos. 1,167 and 1,186, on the "Fresh-water Floods of Rivers," occupied the whole evening, to the exclusion of any other subject.

February 18, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,187.—"The Supporting Power of Piles; and on the Pneumatic Process for Sinking Iron Columns, as practised in America."[1]
By WILLIAM JARVIS M'ALPINE, M. Inst. C.E.

THE absence of any reliable data in the text-books, upon the weight which may be safely imposed upon piles, has led the Author to present the subject for the consideration of the members of the Institution, under the hope that it may call out the recorded experience of other Engineers, for the purpose of comparison with, and perhaps a correction and extension of, the formula prepared from an extensive set of experiments, made for the purpose in 1847.

Mr. Molesworth (M. Inst. C.E.) has published a formula which corresponds with one furnished by Major Sanders, U. S. Engineers, from the results of his experiments at Fort Delaware, in 1849, as follows:[2]—"The pile will safely bear, without danger of further subsidence, as many times the weight of the ram, as the distance which the pile is sunk the last blow, is contained in the distance which the ram falls in making that blow, divided by eight,"—provided the pile moves equally at several of the last blows.

Another formula was published, some years ago, nearly corresponding with one given by Weisbach, as follows:—

$$L = W \cdot \left(\frac{W}{W + W'}\right) \cdot \left(\frac{h}{d}\right);$$

Where W is the weight of the ram in tons, and W′ the weight of the pile in tons, h is the height, in feet, of the fall of the ram, and d the depth which the last stroke drives the pile.

Piles are used under the three following conditions, each of which should be separately considered: First, to compact a soil which is not quite firm enough alone to support the superstructure; secondly, as columns of support, when the material immediately below the structure is very loose or fluid, and is underlaid by a firm material, to, or into which the piles are driven; and thirdly, when the support is mainly derived from the adhesion of the material into which they are driven, and slightly from their sectional area.

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* "Journal of the Franklin Institute." Third Series, vol. xxii., p. 304.

The first two of these conditions will not be discussed; but the present Paper will be confined to the practical hints growing out of the Author's experience in driving a large number of piles, of different kinds of timber, and of different dimensions, and with rams of different weights and falls, and the use of various kinds of power.

The Government Graving Dock at Brooklyn, N. Y., is a structure of granite masonry, weighing 50,000 tons, the walls of which commence 36 feet below the sea level, and the excavation was carried 4 feet deeper. A considerable portion of the foundation had to sustain a weight of 3 or 4 tons per square foot. A line-of-battle ship, weighing 5,000 tons, would require to be mainly supported on its narrow keel within a length of 200 feet, which gives an estimated weight upon the keel of about 20 tons per lineal foot. The grillage and foundation distribute this weight; but the centre piles are probably subjected to a weight of from 10 to 15 tons each.

The material removed from the excavations was a fine silicious sand, mixed with minute particles of mica, and a little vegetable loam, and fully charged with water, rendering the mass somewhat fluid, resembling quicksand, which it did become to a depth of several feet, wherever it was much trodden by the workmen. Borings were made, and trial-piles were driven, to a depth of upwards of 50 feet below the excavation. These indicated the same character of material to that depth, and it was believed to extend 50 feet, or more, below the borings.

The structure rested on about seven thousand piles, which were driven in rows $2\frac{1}{2}$ feet apart, and at transverse distances of 3 feet, all from centre to centre. Intermediate piles, of very tough second-growth oak, were frequently driven. The main piles were chiefly round spruce spars, very straight, from 25 feet to 45 feet long, averaging a driven length of 32 feet. They were not less than 7 inches in diameter at the smaller end, and, on an average, 14 inches in diameter at the larger end. The heads of the piles were always protected in driving, by bands of iron 3 inches by 1 inch, and occasionally iron shoes were used; but they did not increase the penetration, as the resistance was chiefly from the lateral friction, and the tenacity of the pointed wood was sufficient to displace the material at the bottom.

During the progress of this portion of the work a careful record was kept, which showed the distance moved by every blow on every pile used in the structure, and the weight and fall of the hammer at each blow. From this record it was ascertained, that the number of blows required to drive six thousand five hundred and thirty-nine piles in the foundation an average depth of 32 feet, was two and one-third to each foot of pile, and the distance moved

uniformly diminished from the first to the last blow, ranging from 8 inches at the beginning to no movement at the end, and the average distance driven by the last five blows was 1 inch. The effect of driving the intermediate piles, by compressing the material, was to bring them all to the point of ultimate resistance.

The piles were secured at the top by a mass of concrete masonry, 3 feet around the heads, and by a grillage of timber, plank, and concrete, $2\frac{1}{2}$ feet thick on the top.

The piling machines were strongly and accurately made, with the ways bound with smooth plates of iron. The rams were of cast iron, swelled out at the bottom, to concentrate the weight at that point. They weighed generally about 2,200 lbs.; but some were used of 1,500 lbs. The leaders generally gave a fall of 30 feet to the ram; but some machines were tried with leaders of various lengths up to 57 feet.

A considerable number of piles were driven by a Nasmyth steam piling machine, with a ram of 3 tons, and a stroke, or fall, of 3 feet, and making from sixty to eighty strokes per minute. The other machines were generally operated by steam-power, giving an average of a blow per minute; but occasionally the hammers were hoisted by manual or horse power. It was observed that the heaviest ram, when striking blows of the same effect as lighter ones, did the least injury, either to the head of the pile or to the protecting iron ring, and this injury was still less with the Nasmyth hammer. It was also found that no advantage was gained by increasing the fall of the ram beyond 40 feet, as the friction on the ways then prevented any increased velocity to the ram when falling from a greater height. This experiment was repeated many times in the machines with the longest leaders, by tripping the hammer at various heights, from 35 feet upwards, until the maximum penetration of the same pile was ascertained.

A few of the piles, under peculiar circumstances, had to be driven with a follower, which was made of very tough oak, and well banded at both ends. The effect of the blows of the ram was about one-third as much as when directly striking the head of the pile.

The Nasmyth hammer was capable of driving the piles to a much greater depth than any of the other machines; and although the force of its blows is much less than those of the ordinary rams when falling nearly 30 feet, it produces a much greater effect. With the former, piles were driven 35 feet in seven minutes, while with the other machines similar piles required one hour, or more, to drive them the same distance. Two trial piles were driven with each of these machines, with the following results:—

TABLE I.

Pile driven by the Nasmyth Machine.

The first	4	blows	drove it	4	inches	at each blow.
„ next	8	„	„	$3\frac{1}{2}$	„	„
„ „	22	„	„	3	„	„
„ „	25	„	„	2	„	„
„ „	40	„	„	$1\frac{3}{4}$	„	„
„ „	56	„	„	$1\frac{1}{2}$	„	„
„ „	32	„	„	$1\frac{1}{4}$	„	„
„ „	64	„	„	$1\frac{1}{8}$	„	„
„ „	73	„	„	1	„	„
The last	49	„	„	$\frac{1}{2}$	„	„

This pile was nearly the same size as the other trial pile, and was driven 43 feet in seven minutes, with 373 blows, and was not iron-shod.

TABLE II.

Pile driven by a Ram weighing one Ton, falling from $\frac{1}{2}$ to 35 feet.

The first	100	blows	drove it	a few feet.
„ next	260	„	„	30 inches in all.
„ „	265	„	„	from $\frac{1}{2}$ to $1\frac{1}{2}$ inch at each blow.
„ „	110	„	„	$1\frac{1}{4}$ inch at each blow.

This pile was driven 45 feet with 735 blows. It was 20 inches in diameter at one end, and 14 inches at the other, and was shod with iron, and occupied 166 minutes in the driving, viz., 264 blows in 46 minutes, 265 blows in an hour, and 110 blows in an hour.

The ordinary piles were smaller and shorter than these trial piles, and the ram in the common machines began with a greater fall than above stated on the trial pile; and there was not so marked a difference between the two machines in the first part of the operation, as was shown afterwards, when the pile had penetrated deeper. At first, the force of the blows in each of the machines was absorbed by the vibrations of that part of the comparatively slender elastic column which was above ground; but when it had been driven a considerable distance into the earth, these vibrations for the instant removed the partially fluid material from contact with the pile for nearly the whole of its penetration. In the case of the Nasmyth machine, the blows succeeded each other at intervals of a second of time, and before the material which had been displaced by the vibrations of the preceding blow could subside again into close contact with the sides of the pile; and, therefore, nearly the whole force of its blows was employed in the displacement beneath the pile. In the other machines, the blows were given at intervals of a minute, by which time the vibrations caused by the preceding blow had ceased, and the semifluid material had partially subsided around the pile, so that a considerable portion of the force of the blows was consumed in overcoming the friction along the sides, and in the removal by new vibrations, leaving only

a comparatively small part of the force to displace the earth at the bottom of the pile.

As before stated, the pile derives its support mainly from the frictional surface in contact with the earth, which is measured by the force of the blow, due to the weight and velocity of the ram. The ram, however, does not fall in free space, but meets with great resistance along the ways, depending upon their smoothness, and the strictly vertical position of the machine at all times. In wet foundations the material obtains a degree of fluidity, when disturbed by the operation of driving, which lessens the resistance to the penetration of the pile; but the superior gravity of the earth to that of the water causes it subsequently to settle in close contact with the sides of the pile, and, if not afterwards disturbed, gives a greater coefficient of support than if the same pile had been driven through the same kind of material in a dry state. In using comparatively slender piles, the vibration caused by the blows enlarges the passage, and loosens the material; and, although they absorb much of the power, they doubtless increase the penetration at each blow. It would be hazardous, however, to trust to the effect of this subsidence in a superstructure which is liable to vibration, and to convey these vibrations to the piles; but when there is a large mass of matter intervening, like that of the masonry of the piers of a bridge, there is no danger from this cause.

Experiments were made at different times during the progress of the construction of the dry dock, to ascertain the weight which the piles driven in the manner described would sustain. For this purpose one end of a lever of oak timber, 60 feet long, was firmly secured to a cluster of piles, with a short arm resting on the trial pile. The bearings were angular steel bars, resting on planed plates of iron. The outer end of the lever was slowly weighted with successive weights, which, towards the latter part of the trial, were allowed to remain several hours, and in a few cases a whole night. A number of the foundation and cofferdam piles were withdrawn by a similar process, and the power required was also ascertained. Many of these trials were made on piles of nearly the same size, and driven in exactly the same manner, and the results were in all cases nearly alike, giving 125 tons as the weight required to move a pile, driven 33 feet into the earth, to the point of ultimate resistance, with a ram weighing one ton (2,240 lbs.), and falling 30 feet at the last blow. These trial piles averaged 12 inches in diameter in the middle.

The complete record of the driving, before referred to, also enabled the selection of piles, for some other experiments, of different sizes, and driven with rams of different weights and falls. As these trials had to be continued until the final weights applied produced a visible movement of the pile, and, as some allowance

must be made for the friction and imperfection of the lever attachments, and from the support of the sectional area of the pile, it was believed that the extreme supporting power of the pile, due to its frictional surface, was 100 tons, or 1 ton per superficial foot of the area of its circumference.

From an analysis of these experiments, the following general laws seem to have prevailed in these cases:—1st. That the effect of lengthening the fall of the ram was to increase the sustaining power of the pile (driven as before mentioned) in the ratio of the square root of the fall. 2nd. That by adding to the weight of the ram, the sustaining power of the pile was increased by 0·7 to 0·9 of the amount due to the ratio of the augmented weight of the ram. 3rd. That a pile driven by a ram weighing one ton, and falling 30 feet, will sustain an extreme weight of 100 tons.

The formula based upon these data, as applicable to rams weighing from 1,000 lbs. to 3,000 lbs., falling from 20 to 40 feet, was as follows:—Let W represent the weight of the experimental ram, and W′ that of any other ram. Let F represent the fall of the experimental ram, and F′ that of any other ram. Let Y represent the extreme supporting power of a pile driven by the ram W, falling a distance F; and X the supporting power of a pile driven by the ram W′, falling a distance F′. In the experiment W = 1 ton; F = 30 feet, and Y = 100 tons. W′ and X are in tons. and F′ in feet. 1st. With the same weight of ram as in the experiment and any other fall $F : \sqrt{F'} :: Y : X$, $X = 18{\cdot}25\sqrt{F'}$, 2nd. With the same fall and any other weight of ram,

$$X = 0\,.\,8\left(\frac{Y\,W'}{W} - Y\right) + Y \quad . \quad . \quad X = 80\,W' + 20.$$

Combining the two results $X = 80(W' + 0{\cdot}228\sqrt{F'} - 1.)$

The following is a comparison of the results obtained from the formula before referred to, and the one above stated, using the dry-dock experiment.

1. Weisbach. $X = \left(\frac{W'}{W}\right)^2 . \left(\frac{w\,F'}{s}\right)$ when the characters are the same, except that W is expressed in lbs., and w represents the weight of the pile, and s represents the average penetration of the last ten blows of the ram. w = 560 pounds, and s = 0·04 foot, by assumption, although it was really nil in the dry-dock experiment —X = 120 tons; or, if s is reduced to 0·01 foot, X = 480 tons.

2. Molesworth. $X = \frac{W'\,F'}{8\,s} = 90$ tons; or, if s is made 0·01, then X = 360 tons.

3. M'Alpine. $X = 80\,(W' + 0{\cdot}228\,\sqrt{F'} - 1) = 100$ tons, with $s = nil$.

Weisbach remarks that "for safety, the pile should not be loaded with more than from one-hundredth to one-tenth of this result;" and Molesworth gives his result as the "safe load."

The Author is of opinion that, under the most favourable circumstances, the pile should not be loaded with more than one-third of the result given by his formula; and where there is any danger of a future disturbance of the material around the pile, or where there is any vibration in the structure which may be communicated to the piles, the load imposed should not exceed one-tenth.

In the preceding discussion, the bearing support due to the sectional area of the pile has not been considered, as it forms so small a portion of the support. Numerous experiments have been made which give results of from 5 tons to 10 tons per square foot.

In 1861, the Author made some careful experiments of the supporting power which was derived from the frictional surface of large cast-iron piles, 6 feet in diameter, sunk from 20 feet to 30 feet in rocky gravel, which gave a result of about $\frac{1}{2}$ ton per superficial foot of frictional surface. These piles were sunk by the pneumatic process (both plenum and vacuum), and he now proposes to describe the method of sinking them.

The island occupied by the city of New York is separated from the mainland by a navigable tidal estuary, called the Harlem River, extending from Long Island Sound to the Hudson River, of from 600 to 1,800 feet in width, and is spanned by several bridges, among which is one of granite carrying the Croton Aqueduct. It is 1,300 feet in length and 160 feet in height, on fifteen arches of 80-feet span, giving a clear headway above flood tide of 100 feet.

The Third Avenue is one of the principal thoroughfares leading out of the city, and was carried across the estuary by a wooden pile bridge, built at the beginning of the present century.

The new structure was designed in iron, with a pivot draw, giving two clear passages of 80 feet each, and two shore spans each of 120 feet in the clear. The width of the bridge was arranged to carry a railway track, two carriage-ways, and two wide foot-walks. With a view of creating the least possible obstruction to the current, the draw-pier was arranged to consist of one central and ten circumscribing iron columns, each 6 feet in diameter and 50 feet in height, surmounted by girders of cast iron, on which the draw-table revolves. The other piers and abutments were designed to be built of granite masonry, but have been changed to iron columns.

The work was commenced in 1860, and the columns for the draw-pier within a year, after which the Author left the work. Various delays and suspensions of the work occurred, and the

bridge was not opened for public use until the present year (1867), owing to want of accord between the Municipal and State authorities, and to disputes with the contractor.

The work, as completed, varies in many important particulars from the original design. In the Author's opinion, the changes have not increased either the strength, durability, efficiency, or architectural effect of the structure. The original plans would have been carried out at less than one-third the present cost.

The margin of the river, near the site of the bridge, is occupied by wharves, which have contracted the channel, and produced a tidal current of 5 or 6 miles an hour. The fluctuations of the tide are from 5 to 8 feet. The draw-pier, if built of masonry, to accommodate the great width of the draw when open, would have occupied more than one-eighth of the channel. To lessen this obstruction, the substitution of iron columns was considered, and further examination showed them to be less expensive than a pier of masonry. These reasons did not apply to the other piers, and especially to the abutments.

The Author's attention was first directed to the use of hollow iron piles sunk by this process, for the foundation of the Government Graving Dock, at Brooklyn in 1846; but at that time this method had not been much used, and the only information on the subject then accessible to him, was a small pamphlet by Dr. Potts, the inventor, and a copy of his patent claim. In 1850 Mr. L. J. Fleming recommended the use of cast-iron piles, sunk by Dr. Potts' pneumatic process, for a railway bridge across the Peedee River, in North Carolina; and in the following year Major Walter Gwynne, the chief Engineer, adopted the plan, and engaged Mr. Fleming to carry it out, which was done during the ensuing two years. One of the piers of this bridge was formed of four columns, placed in pairs close together in the line of the bridge, and 10 feet apart transversely to its axis. Another pier was formed of three columns 2 feet apart. The spans were 135 feet. The columns were 6 feet in diameter, the metal 2 inches thick, and the whole height 50 feet. They were first sunk 13 feet into the sand, and, subsequently, from 5 feet to 15 feet further into the shale. The work was commenced with the use of the vacuum process; but the first pile encountered a cypress log 5 feet in diameter, and a plenum was used to expel the water and remove it; after which the latter process was almost exclusively employed. A few years later the same Engineers applied this method for a bridge across the Santee, in South Carolina.

In 1860, General W. S. Smith, U.S. Army, commenced the construction of similar piers for a railway bridge across the Savannah River, in Georgia, but was compelled to suspend the work after a few of the piers had been erected, in consequence of

the breaking out of the civil war. These, with the Harlem Bridge, are the only examples of the use of this process in America.

Before commencing the discussion of the subject, the Author furnishes extracts from his journal, giving a full description, in detail, of the method adopted at that place; and the various experiments and tests are taken from notes made at the time.[1]

The first column having been sunk to the estimated necessary depth to give it the required sustaining power, it was indispensable to determine the resistance which the material in contact with the exterior of the pile would actually afford. Measures were therefore taken to apply a powerful pressure to the column, by means of a trussed lever, which had already been prepared for this purpose. It was considered that the coefficient of adhesion at first given by this experiment would be considerably below what might be expected at a later period. The constant bubbling up of the air through the earth and water, for an area of 40 feet in diameter around the pile, showed that the material in contact with it, and for some distance beyond, had become much loosened by the escape of the air, which occasionally rose to 37 lbs. pressure per square inch, equal to a hydrostatic head of 85 feet, and by the washing out of the finer portions at every influx into the column. This weakened adhesion was also shown by the ready descent of the column, even at this great depth, when unobstructed by boulders.

The operation of sinking No. 2, the side of which was but 6 feet from that of No. 1, maintained this condition of the material around the latter for at least one half of its area, as in its loosened state it gave a more free vent for the escape of the surplus air from the former. By the lapse of time—the action of the currents—the superincumbent weight of the water—and the constantly diminishing effect of the operations carried on in sinking the neighbouring columns,—the loosened material will gradually settle, and the finer particles infiltrate between them, and restore it to nearly its normal condition. But it was thought advisable to determine, not only the resistance of the material in its loosened condition, but also the ratio of increase from this silting, by repeating the experiment at intervals. The lever was placed in position on No. 1, and great pains taken to secure the fulcrum from any upward movement, the uplift by its leverage being fourteen to one, estimated at about 1,000 tons. The platform had not been built strong enough to bear this weight, and the hold of its piles, placed 8 feet apart, had been weakened by the escape of the air from the columns, through the materials around them. A system of trussing and tying these piles was adopted, by means of which the resistance of from ten to

[1] These extracts are so voluminous that they have not been printed, but they may be consulted at the Institution.

twelve of them was obtained. The heavy chain guys of the large derrick were carried forward as well as aft, and strained by powerful tackle, thus making them form a truss, by means of which the resistance of as many more piles was obtained. The platform was also loaded, and some other expedients resorted to which enabled the leverage of 700 tons to be resisted; but the continuance of the experiment was unfortunately prevented by the hold of the fulcrum finally yielding to the great stress brought against it. The depth of earth in contact with the column was found by sounding to be 19 feet 5 inches on the outside, which gave a superficial area of 365·7 square feet.[1] The lever was of Georgia pine 60 feet long, averaging 18 inches by 16½ inches scantling. The short arm was 4 feet long. The bearing points were round steel rollers, 1½ inch in diameter, and 12 inches long, turned and resting in grooves planed out of heavy iron castings. The lever was strongly trussed by a king-post of oak, 9 feet high, 13 inches square, resting on a cast-iron bearing plate, and arranged with folding wedges at the bottom to strain the truss to its greatest tension. A heavy cast-iron saddle was fitted to the top, through which passed a strong iron pin. The long truss rods were two bars of iron, 2¼ inches by ¾ inch section, the shorter ones three rods of 1⅞ inch, connected to a joggle, and by two links of 1⅝ inch to lugs on the lever beam. Heavy cast-iron plates, with lugs, were bolted to the outside edge of the lever beam, to which the long truss bars were attached. As the top of the column was 8 feet below the top of the platform, a blocking of solid timber was built up to support the iron plate which carried the steel bearing pin. The truss was destined to allow a strain of 150 tons to be thrown on the column, but would probably have carried twice that weight for a short time. At the commencement of the experiment, the long end of the lever was raised about 10 feet above the horizontal, by means of a small derrick, and after the different parts of the apparatus had been adjusted, the tackle that held it was slackened, and the end sunk 4 feet, bringing home the lashings and adjustments, and throwing the weight and leverage of the beam on the column. The weights were then applied at the end of the long arm of the lever, consisting of chains looped over it and pigs of cast iron. The insistent weight on the column, consisting of the blocking, king-post and castings, was 3,636 lbs. The first 40 feet of the lever beam weighed exactly 100 lbs. per lineal foot, which with an average leverage of 20 feet against 4 feet for the short arm, gave 20,000 lbs. on the column. The outer 20 feet of the beam weighed 90 lbs. per lineal foot, and had 50 feet leverage, giving 22,500 lbs. The outer

[1] During the operation of sinking, the influx of material into the column had depressed the surface of the river bed immediately around it 6 feet in depth.

casting near the end of the lever weighed 75 lbs., with 52 feet leverage, which gave 977 lbs. The two long truss bars, weighing 630 lbs., with a leverage of 28 feet, gave 4,410 lbs., making the leverage weight 47,887 lbs. The rods, toggles, and links on the short end of the lever weighed 476 lbs., and gave a leverage weight of 211 lbs. This gives a total pressure on the column of 51,734 lbs., or 25·86 American tons,[1] as due to the apparatus alone. A load of 2,145 lbs. of chain was applied at a point 58 feet from the fulcrum, which gave 31,102 lbs. additional weight on the column, making a total of 41 tons. This sunk the lever to a horizontal line (6 feet more) caused by the indentation of the chain lashings into the wood, and the further bringing home of the several parts of the apparatus. Afterwards, two more experiments were made, the first throwing a strain upon the column of 49 tons and the second of 55⅓ tons. The severe strain now brought against the fulcrum caused some yielding, and it was accordingly further secured by strong trusses, and also by taking advantage of the weight and assistance of column No. 2, then partly sunk.

It should be mentioned that this work was carried on in the middle of the river, where the water was 20 feet deep, and it would have been very expensive to have secured the fulcrum by any other means. On the 11th February a fourth trial was made. The resistance of the column in its then condition depended only on the outside clasp of the earth. The interior had been excavated to the bottom, and the material below it was free from stones or other resistance. The forward end of the lever was hoisted 14 feet, and the bearing blocks were keyed up. It was then lowered, and weights successively added until there was a strain of 65½ tons on the column. The holding-down trusses did good duty, the chains being gradually tightened until they became as rigid as iron bars. The biting of the chain lashings about the fulcrum and piles into the solid wood, and the compressing together of the bearing timbers, showed the great force employed. A measurement at the column now showed no further settlement, it having gained its full bearing by the former trials. The settlement on the first trial averaged ½ inch, being least on the east side, a little more on the south, and greatest on the west. On the second trial there was no settlement on the east side, ⅛ inch on the west and ⅜ inch on the south, averaging less than ¼ inch. On the fourth trial no settlement could be obtained. The weights brought upon the column by these trials were respectively 41, 49, 55, and 65½ tons, exclusive of the weight of the column itself, which was 31 tons.

It will be seen that on the three first trials a settlement of 1 inch

[1] The legal ton in most of the States is 2,000 pounds, except in articles of foreign manufacture.

was obtained, of which one half took place on the first, made one week after the sinking was finished, and one-third on the third trial, while the work on No. 2 again disturbed the material around it. The position of the lever was nearly on the meridian line, with the short end to the south. No. 2 was 6 feet to the eastward. The strain at the fourth trial was 131,141 lbs., which, added to the weight of the column, 62,190 lbs., gives a total supporting power of nearly 97 tons. The area in contact with the earth was 366 square feet, which divided into 193,331 lbs., gives 528 lbs. per foot; and as the column did not settle, its sustaining power was evidently greater than this load, even in the then loosened condition of the earth. A subsequent trial, which was not entirely trustworthy, indicated that 100 tons would not move it, which gives 716 lbs. per superficial foot.

In the set of experiments made in 1847, previously described, the Author ascertained that the bearing support of wooden piles driven into fine sand was 1 ton per superficial foot of surface, when driven to the point of ultimate resistance, with a ram weighing 1 ton, and falling 30 feet. Although it was impossible to drive the trial piles at the Harlem River to the same depth as the iron columns, in consequence of their meeting with stone, yet it is probable that they would have been driven to the same depth as at the Brooklyn Navy Yard had it not been for these obstructions, and that the support given by the superficial area of the iron columns would be at least three-fourths as much as that of wooden piles, or $\frac{3}{4}$ ton per square foot.

The frictional resistance depends upon the surface in actual contact, which in the minute divisions of the fine sand at the Navy Yard must give the largest co-efficient of resistance. At Harlem, the silting of the same kind of fine sand between the interstices of the larger particles, gravel and stone, would give nearly, but, probably, not quite, as large a co-efficient. A slight indentation of some of the angular particles of sand into the wooden piles, which does not take place with iron, and the more uneven surface, also increases the resistance.

The experiments described were all made while the material around the column was maintained in a loosened condition; and after a careful consideration of all the circumstances of the case, the Author has adopted a co-efficient of $\frac{1}{2}$ ton per superficial foot of the exterior surface of iron piles in moderately fine material. In ordinary wooden piles, the support from their sectional area is comparatively small; but it becomes an important element in such large iron piles as those at Harlem, as it increases in the proportion of the squares of the diameters. Thus, at the latter, this support is six times as great as at the Navy Yard.

This led to the consideration of the practicability of expanding

the base of these columns after they were sunk. Although the lateral support, as determined by the experiments, in addition to that which would be derived from a base of 6 feet in diameter, showed that it would be ample for that place; yet, in view of subsequent operations, the importance of devising a method of increasing even the large base due to the size of the column offered advantages too great to be neglected, and various methods of accomplishing this result were suggested. Among others was that of using very thick iron wedge-shaped plates, with deep flanges, to be driven out horizontally under the lower rim, or the use of small short screw piles, placed round the inner circumference, or of narrow segmental iron-sheet piles, sloping outwards, beneath which the excavation could be made and refilled with masonry. The circumstances of the case did not warrant the expense of either of these methods; and, therefore, the following one was adopted:—It had already been decided to fill the columns with concrete, and it was naturally suggested to extend this below the bottom as deep as men could work in the water, and also to undermine the adjacent earth, as far as practicable, and to extend the concrete into the space. The bottom of the column was 47 feet below high water, and the superincumbent mass of earth was 20 feet deep, and to sustain the latter sheet piles of oak plank 5 feet long, 3 inches wide, and $1\frac{1}{4}$ inch thick were driven by hand under the edge of the column at an angle of 30° from the horizontal. This was done in sections of about 2 feet in width, and the excavation was made outward with as great rapidity as possible, and the concrete being in readiness was also put in place without delay; the best and most active workmen being selected for this operation, as the sheet piling did not prevent for more than a few minutes the fluid sand above from rushing into the excavation, and it was often questionable whether the concrete or the sand would first occupy the space. At first this plan almost proved a failure; but with a little practice and familiarity the habit of the material under the peculiar circumstances was learned; and it was found that by working the air-pumps rapidly, and sending in the maximum quantity of compressed air for some hours before, and during the operation, the water was driven in a great degree out of the sand, which then possessed more adhesion, and more time was given before it began to run into the space excavated. The workmen also learned not to attempt excavating for a second section immediately alongside of the first, but to go to the other side of the column, where the material had not been disturbed; then to the two points at right angles, and afterwards to gradually close up the spaces between these four points on the circumference, always taking opposite points. After the first four places were filled with concrete, they seemed to afford considerable support to

the material, and the operation was less difficult. The men learned by practice after an excavation was commenced, whether it was judicious to continue it, to wait for a longer continuance of air pressure, or to make the attempt at some other place on the circumference. The appearance of the sand becoming suffused and changing in colour, occasioned by the advance of the water, was a sufficient hint to stop for the time being, and wait until it was compelled to retire before the action of the compressed air. When the ring had been completed, it was found that the column was virtually extended, and that the water would readily sink under pressure to a level with the bottom of the concrete, so that the sand within it was easily removed, and the space filled with concrete to a depth of generally 4 feet, or more.

In some discussions in regard to the use of concrete under pressure, it has been stated that it would not set sufficiently to serve the purpose intended. In the Author's experience, he has found that concrete subjected to hydrostatic pressure would not set, and that the water would push its way through the mortar in the interstices of the stone before the cement has had time to harden sufficiently to resist it. This effectually prevents any aftersetting of the mass; and would render it unfit for use in the columns, except for the pneumatic pressure, which in some way counteracts the effect of the hydrostatic head against the lower part. In consequence, however, of its fluctuations, while the hydrostatic pressure is uniform the cementation of the mortar is partially destroyed. The upper surface, in contact with the air, sets very quickly, so that the rest of the mass derives very little or no benefit from the air pressure, unless means are taken to bring it in contact or opposition to the force of the water. This difficulty, it is thought, has been overcome in a satisfactory manner, by the use of small vertical pipes leading downward to the bottom of the concrete, and placed within 1 foot of each other over the whole area of the column. The pneumatic pressure is carried by these pipes below the concrete, when it forms a film of greater or less thickness in immediate contact with the water, and so prevents the latter from disturbing it. Contrary to statements occasionally made, the cement is found to set with far greater rapidity under pneumatic pressure than in the ordinary atmosphere. So quickly did this take place in the case in question that in the few minutes required to take the concrete through the air-lock and down to the bottom, and put it in the place designed, it would sometimes become so hard as to make its removal from the bags troublesome, and would not again set. Water had occasionally to be used, and the mass stirred to keep it moist, and retard the setting until the workmen were ready for it.

The consideration of the importance of the expanded base, as

affording so large an increase of the supporting power of the column, at so small a cost, suggested, during the progress of the concrete method, still another plan, to be used in conjunction with, or separately from it, as might be deemed expedient. This was, to make the lower cylinder conical, with its bottom diameter as much greater than that of the column as might be found judicious. As there would be a diagonal strain upon this section of the column, the thickness of the metal would have to be increased to make its strength equal to that of the other parts. It is believed that this additional area of the bottom would not only be no obstruction to the sinking by the pneumatic process, but would facilitate it. As this expanded width cleared the way for the narrower column above it the friction would probably be less, for at least a portion of its length; and its interior vertical wedge-shaped section would not be an obstruction when it was entirely cleaned from any material, and when the inrush of the water made the earth or sand partially fluid. Even if this form of the lower cylinder somewhat retarded the sinking, it would give so large a support, when down in its place, as to warrant some extra trouble. The concrete expansion could also be used in addition to the conical form of the lower section, and thus a largely extended base be formed for the column to rest upon.

Some further extracts from the Author's journal are then given, showing the improvements which were effected, and the methods adopted for overcoming the obstacles afterwards encountered.

The experience gained, and the reflections resulting from the operations at the Harlem Bridge show, among other things, the rapidity, facility, and economy of sinking iron columns of large size, under favourable circumstances. The extracts from the journal show that the last columns were sunk from 16 feet to 20 feet in from three to six days, in sand and porous material, free from obstructions, and with experienced workmen, and of 8 or 10 feet diameter, with as much facility as smaller ones. The economy of this work is indicated by the small force employed at Harlem, which was twelve men, all told, including the engine-drivers, stevedores, and foreman. Their aggregate wages, and the expense of fuel, did not exceed £6 per day. The cost of the plant was under £1,500 The metal in the column, if but $1\frac{1}{4}$ inch thick, which is quite sufficient, would have been, in New York, £13 per lineal foot of the column.

These columns may be sunk to extraordinary depths. At Harlem, the officers and workmen experienced neither temporary nor permanent ill effects from a pressure of two and a half atmospheres. Mr. Charles L. McAlpine recently stated, before a convention of Engineers, that, "He had been in the habit of entering the column daily (at Harlem), and had occasionally spent six hours

or more, in the condensed air without perceiving the slightest effect. These columns had been sunk to a depth of 50 feet below the water; but it was often necessary to raise the pressure to 37 lbs. above the atmosphere, to expel the water through the strata of compact material. This was equal to an hydrostatic head of 85 feet. The only time when any difficulty was experienced was when entering or leaving the airlock, from or to the outside atmosphere. Men of nervous temperament, who gave way to excitement, usually added to their difficulty by keeping their nerves under great strain; and some of them suffered greatly, the blood starting from the nose, ears, and mouth, and the pressure upon the eyeballs and drum of the ear being very painful. No trouble, however, was experienced in obtaining men who could bear the change of pressure without injury; and a little practice familiarized them to the circumstances. The muscular action of swallowing always relieved the tympanum temporarily. They did not hesitate to 'equalize' in going inside as fast as the means allowed, or in less than a minute. When under pressure, it would be difficult to detect an increase of even one atmosphere. The pressure produces great exhilaration, the ventilation is complete, breathing easier, the inhalations being slower and shorter, and the pulse very slightly increased. Upon again entering the atmosphere, the absence of the stimulus of so much oxygen produces lassitude for a time, but no other difficulty. At the end of a year no effect prejudicial to the health or constitution was observed. Some of these men have recently applied for the same kind of employment. We paid them fifteen per cent. more than ordinary labourers; but this was because we selected a more intelligent and better class of men. During the whole time, they worked the regular ten hours (under pressure), and frequently several hours extra. They became so indifferent to the effect, that, instead of coming out at the end of two hours, they preferred to remain within for the ten or fifteen minutes required to empty the sand-bags, and were very often found asleep on a platform near the bottom, on the return of the foreman. The only condition they made was, that my brother or myself should always take the management of the operations while they were in the column, in order to guard against any carelessness. It gives me pleasure to say that no accident ever occurred."

The Author frequently descended the column when any of the more delicate or interesting operations were being conducted, and sometimes remained several hours, and can personally confirm the above statements of his brother, in regard to the effect of the increased air pressure upon the human system. His own health was positively benefited.

Cylinder piles can be sunk through extraordinary obstacles, such as rocks, logs, and sunken vessels, without serious loss of time, or at

much cost; and they will penetrate quicksands, which are so troublesome by all other methods, with unusual facility. The sinking of column No. 10 a depth of 20 feet in thirty days, through a continued mass of boulders, many of which were of large size, and required to be drilled and split (powder would be inadmissible) under water,[1] showed that even under these unusually difficult circumstances, the time occupied in sinking this column was only three times that required for the ordinary ones, and in No. 5 but two days were occupied in forcing it bodily through a wrecked vessel. These immense weights of 40 tons may be handled by simple and inexpensive machinery; and the columns may be regulated in their descent, or be suddenly arrested at any precise point, at the will of the director, by means of a pneumatic reservoir. Thus the descent was commenced at first slowly, the velocity being gradually increased until the movement became dangerous, when it was instantly stopped. Again the lever was moved at will, and by repeated motions was finally brought within 2 inches of the precise penetration desired.

The extreme precision with which these cylinders can be placed and sunk, and their immobility and great strength against lateral impact or pressure, must not be overlooked.

In some cases the piles can be sunk by the vacuum process alone, and in all cases by the plenum, and sometimes both may be employed with advantage; and the sinking can be further aided by the use of mechanical pressure or weight. When the material below and around the columns proves, for the time being, impervious from within, to water, or air under pressure, the water may be expelled, not only by a common pump, but more simply by the syphon trunk. When such material is permanently impervious, the operations may be carried on with an open column, resorting to the plenum process when the exterior lateral adhesion exceeds the effect of the weight or pressure on the column. This may also, in some cases, be effected by small jets of water forced under considerable hydrostatic head from a suitable number of orifices through the sides of the column, to lubricate and loosen the material.

The support which such columns derive from their exterior frictional surface in ordinary earth is, as previously stated, at least equal to $\frac{1}{2}$ ton per square foot, but in the finest earth it would amount to 3 tons. The support from the area of the bottom in shallow depths is from 5 tons to 10 tons per square foot, and at the great depth to which these columns will be ordinarily sunk, it must be considerably more.

[1] A plan for a drilling machine, to be worked by the condensed air exhausting into the atmosphere, was arranged; but it was not completed in time to be made available.

When the material immediately below the iron bed is liable to disturbance, the dependence for support, in comparatively short columns, is mainly from the area of the bottom. An expanded conical base may be sunk with equal, or greater, facility, and will greatly increase the desired support. The same object can be accomplished in an economical manner, either as a substitute for, or in conjunction with the conical bottom, by extending the concrete filling a suitable distance below, and conically outwards, as far as practicable or expedient; the depth or thickness being increased in proportion to the lateral extension, in order to give the concrete the requisite strength. The expansion of the base gives an amount of support which will admit of a reduction of the diameter of the column, to that which would be required to give it the necessary strength as a column of support merely, and to resist any lateral impact or pressure to which it may be subjected. If it be required to enter the column, it should not be reduced to less than from 20 to 24 inches in the clear.

Hydraulic mortar sets with such extraordinary rapidity and firmness in a concentrated atmosphere, that 6 feet in depth of concrete was found sufficient to resist 40 feet head of water. In some cases, however, it may be advisable to seal the bottom with an iron plate.

An opinion has been expressed that the unequal contraction of the metal and concrete, at a temperature of 50° below freezing, would endanger the iron shell. The experience of the first winter at Harlem, when the mercury fell to within 8° of this point, or 10° below zero, and that of the five succeeding winters, shows that no injury need be apprehended from this cause.

The Author has been informed, that in the intensely cold weather at St. Petersburg, under similar circumstances, the result has been the same as at Harlem.

The corrosion of the metal, even when exposed to the alternate action of air and water, is too little, under ordinary circumstances, to impair the strength of the columns. In salt water or foul water the corrosion might possibly reach a depth of $\frac{1}{10}$ inch in a century. The column may be sealed at the top and the bottom, and so prevent the admission of air or moisture. The quicklime in the hydraulic mortar is said to be a preventive to corrosion.

Thus far, the consideration of the subject has been confined to columns of sufficient strength of shell to bear the imposed weight, either directly upon it, or indirectly through the filling. It may however, be desirable, in some cases, to carry up masonry, on which the superstructure can rest. In this event, the column may be enlarged and conformed to the desired shape of the masonry, and made of thin cast or wrought iron, with suitable removable braces. It would then become an inverted caisson, and would only require

to be made strong enough for this purpose. Its capacity would only be limited by the means at hand to resist the buoyancy from the air-pressure. The Author prepared a design for carrying down the masonry piers of the Harlem Bridge to a depth of 30 feet below the surface of the water, by means of a pneumatic inverted caisson 75 feet long, and 12 feet wide, which was divided into six air-tight compartments with a separate column and air-lock to each; but he believes that the same general idea had been previously practically carried out. In America, where iron is expensive and timber cheap, he has suggested the same thing in wood, with the addition of a direct removable caisson above it, extending to high water. For temporary purposes, a rectangular or circular pneumatic pile, formed of timber and plank, and shod with iron, might sometimes be advantageously used. There are numerous cases where foundations are required to support structures, when wooden piles are inadmissible, from their rapid decay above water, or from the destructive effects of the teredo under water, and the points of support are required at frequent intervals, and the weight imposed not requiring columns of such size as those under discussion. When there are no obstructions, requiring the columns to be entered by workmen, hollow iron piles of a few inches diameter, with an enlarged conical base, may be used with advantage. The material from the interior may be removed by pumps, and the earth on the outside loosened and lubricated by reversing their action and forcing water through the bottom. The pile can be forced down by a fixed weight. The use of an equal insistent weight on each pile would give to the whole of such a foundation an equable support.

[Mr. Gregory,

Mr. Gregory, President, said their American Member, Mr. McAlpine, gave the Institution a mark of his goodwill by a handsome present of books to the library a few weeks ago: he had now furnished another instance by contributing the useful Paper which had just been read.

Mr. H. S. Bethell remarked in regard to the strength and coherence of creosoted timber for piles, that experiments had been made by Mr. Cudworth, of the North-Eastern Railway, and others still more elaborate by M. Forestier, Ingénieur des Ponts et Chaussées at Sables d'Olonne, Vendée, which were worthy the attention of members, as showing the superior vertical resistance and elasticity of creosoted timber over the same description of timber uncreosoted.

"Experiments made by M. Forestier, Ingénieur en Chef des Ponts et Chaussés at Sables d'Olonne, Vendée, for the Paris Exhibition of 1867, on the relative resistance to Crushing Weight, and the relative elasticity of Creosoted and Uncreosoted Timber.

"These experiments were made upon sixty-three blocks of uncreosoted and as many of creosoted wood, and the following Table indicates the mean results obtained for each species of wood. In order to obtain wood perfectly homogeneous in tissue, small cubes, 8 centimètres by 3·88 centimètres square, were selected.

Species of Timber.	Blocks.	Creosote absorbed per Cubic Foot.	Weight required to crush the Uncreosoted Blocks.	Weight required to crush the Creosoted Blocks.	In favour of the Creosoted.	Against the Creosoted.
		lbs.	lbs.	lbs.	lbs.	lbs.
French oak . . .	8	$7\frac{1}{2}$	873	935	62	
Elm	12	$17\frac{13}{16}$	$855\frac{1}{2}$	864	$8\frac{1}{2}$	
Ash	4	$16\frac{1}{4}$	$866\frac{1}{2}$	955	$88\frac{1}{2}$	
Red Swedish fir . .	8	$16\frac{15}{16}$	668	$692\frac{1}{2}$	$24\frac{1}{2}$	
,, Norway fir . .	12	$19\frac{15}{16}$	$921\frac{1}{2}$	$952\frac{1}{2}$	31	
,, Dantzic fir . .	2	$23\frac{3}{16}$	$617\frac{1}{2}$	646	$28\frac{1}{2}$	
White Norway fir .	4	$12\frac{13}{16}$	864	882	18	
Plane	4	25	785	794	9	
Carolina poplar . .	9	34	$595\frac{1}{2}$	569	..	$26\frac{1}{2}$

"To test the relative elasticities, he loaded, in the middle of their length, pieces of oak, elm, beech, plane, red and white Baltic fir, marine pine, Italian poplar, and white Dutch poplar, both creosoted and uncreosoted, measuring 2·50 mètres between their points of support, and 5 centimètres square. After increasing the weight to the point of rupture for several pieces of each kind of wood, he ascertained that the flexibility of the creosoted wood had been sensibly augmented.

"M. Forestier refers to similar statements made by M. Crepin, Ingénieur des Ponts et Chaussés, in the 'Annales des Travaux Publics de Belgique,' after experiments at Ostend.

"A Commission was appointed in Holland in 1858 by the Royal Academy of

Sciences, Amsterdam, in consequence of the breaking of many piles in the port of Nieuwendam, and their Report in the 'Archives Néerlandaises, 1866,' which is in favour of creosoting the piles, confirms in a great measure the statements of M. Forestier and M. Crepin."

Mr. Hawkshaw, Past President, observed that it was not the custom to creosote piles which were to be buried in foundations. For the last two or three years he had been engaged in works in Holland, where nearly every superstructure rested on piles. Many Dutch buildings had stood for hundreds of years, and had not subsided from the decay of the piles. The Dutch plan was to drive larch or fir trees, with the bark on, with the small end downwards; and as the soil of Holland generally was homogeneous and soft, the pile driving usually was easy. The piles were 5 inches or 6 inches in diameter at one end, and 10 inches or 12 inches at the other; and upon them lofty buildings were erected with perfect security. The ordinary method of pile driving was simply to go on driving the pile by a given weight, dropped from a given height, till it went down a given distance per blow. That was the rule, and it was tolerably safe. But not unfrequently in some soils the depression of the pile was not the effect of penetration, but arose from crushing the pile, or splitting and twisting it, until in some cases the point was ascending instead of descending; and thus a large proportion of the labour and expense employed to drive the piles to a given depth was wasted in knocking them to pieces. He thought it desirable to make experiments, with a sufficient number of piles, in every variety of soil, so as to ascertain more accurately in each case the amount of driving which would be equal to any given weight of foundation; and though there was some difficulty in measuring weight by impact, yet results might be arrived at near enough for this purpose. At present there was little doubt that money was not unfrequently wasted in over-driving piles. No doubt it was difficult to devise a formula applicable to pile driving in every stratification, as it was a subject involving many unknown quantities; but if taken up by competent persons an amount of information might be derived which would save a good deal of expenditure in pile driving, in the way in which it was ordinarily carried on.

Mr. G. W. Hemans remarked on the great bearing power derived from the piles described by the Author. In this country the natural tree, with a heavy butt, and tapering to a fine point, would be considered a poor kind of piling. Its good bearing power appeared to have been obtained chiefly by friction, from the piles being driven in a homogeneous stratum, and without reaching a hard bottom. But there was one condition of pile driving to which the formula would not apply, and that was when piles were driven through a weak stratum down to a hard base. Under these cir-

cumstances he had found piles 30 feet or 40 feet long undergo flexure to so great an extent that the abutments of the bridge above gave way. That was a case in which piles of the slight nature described in the Paper would give way at once, and of course the formula would not apply: therefore the inquiry might extend to the proper nature of pile driving under such conditions.

With regard to what was stated about iron cylinders, he had occasion, many years ago, to put Dr. Potts's, or the vacuum principle, into practice with cylinders 10 feet in diameter, and he found it inoperative. A vacuum represented by about 18 inches of mercury was the utmost he could obtain, and the progress of sinking was so slow, that it was abandoned and other measures were taken. Where boulders or similar obstacles occurred it was not a suitable plan to adopt.

Mr. J. A. Longridge was, many years ago, employed by Mr. George Stephenson in a project for crossing Morecambe Bay, which was never carried out, when a question arose as to how far it was practicable to carry out a system of pile driving in loose sand. He made experiments to ascertain the frictional surface of the pile, as there was no real foundation; and the result of these experiments led him to the conviction that it was impossible to establish any formula; but he came to the conclusion that where there was a steady weight, without vibration, it was possible to ascertain what weight the pile would carry, and the depth in the sand to which it was necessary to drive it. But where the structure was a light viaduct, over which trains ran, the results were unreliable, and under such circumstances he found its bearing capacity would be reduced to one-fourth or one-fifth of what it would be where there was no vibration, and the piles would gradually sink. In founding a large bridge upon a sand or a quicksand, he believed the best plan to adopt was to excavate the sand beyond the reach of scour, and insert a large mass of concrete, and upon that build the masonry. He did not think piles of much use in such a case; but the concrete without the piles was as good, provided the water could not scour beneath the foundation. In a girder bridge of 180 feet span, which was built on a quicksand on the verge of the Sunderbunds near Calcutta, ineffectual attempts were made to put in the foundations with cylinders 20 feet in diameter; then 4-feet cylinders were tried, but they could not be sunk. Ultimately there was deposited a mass of concrete 60 feet long, 20 feet wide, and 20 feet thick, the bottom being about 70 feet below the girder level, and on that the masonry was built and the girders erected, and the bridge had proved perfectly stable. Therefore, provided there was no scour, he thought a fluid foundation was as good as could be wished for, and he thought that driving piles under such conditions was unnecessary.

Mr. Phipps remarked that the formula proposed by the Author for determining the resisting power of piles differed from the formulæ of the two authorities quoted, Weisbach and Molesworth, as by their application to perfectly similar cases, the following results were obtained :—

	Bearing Power.	
1st. M^c^Alpine . . . . Weight of ram, 1 ton; fall, 30 feet; penetration, Nil.	100 tons.	By experiment and formula. $\frac{1}{3}$rd to $\frac{1}{10}$th, to be applied according to circumstances, which he describes.
2nd. Weisbach . . . . Weight of ram, 1 ton; fall, 30 feet; assumed penetration, 0·04 foot.	120 tons.	By formula. $\frac{1}{10}$th to $\frac{1}{100}$th, to be applied according to circumstances, which are not described.
3rd. Molesworth . . . . Weight of ram, 1 ton; fall, 30 feet; assumed penetration, 0·04 foot.	90 tons.	By formula. Safe load, which may be applied without alluding to special circumstances.

In examining the leading distinction between the formulæ of these various authorities, it was apparent that in the one case, before the formula could be applied, it was necessary to assume some given distance through which the pile should have penetrated for one blow of the ram, whilst the Author's formula took no cognizance of that fact, and supposed no penetration whatever for the blow to which it was to be applied. It was to these different manners of considering the subject that the distinction in the formulæ was to be traced ; the first leading to the adoption of the full fall of the ram as the measure of the resistance, under equal penetrations of the pile, while the Author's system put that measure as the square root of the fall, with a penetration nil.

It appeared that these differences in the formulæ adverted to could be quite reconciled by a proper consideration of the consequences arising from compressibility in the material composing the pile, for the moment this property was imported into the consideration, it was easy to see that the *vis viva* of any given blow was absorbed sometimes partly by compressing the pile, and partly by penetration, or, it might be, entirely by compressing the pile. The resistance to compression of the pile would be measured by the square root of the fall of any given ram, because the compressing force and distance compressed increased *pari passu*, while the resistance to penetration might be taken in the inverse proportion of the penetration to the fall. In proportion, therefore, as one or other of these limits was approached—of much penetration with little compression of the pile, or *vice versâ*, the one or the other of the formulæ proper to be used would be found. The Author had stated that the application of his formula was to be made to the case of piles, apparently no longer descending by a blow of the ram, the *vis viva* of which was therefore entirely absorbed in compressing

the pile, and consequently the resistance was properly measured by the square root of the fall.

He had calculated that the compression of a timber pile, 30 feet long, at 1 ton to the square inch—the pressure corresponding to the Author's 100 tons—would be about $\frac{3}{8}$ths of an inch, the passing through which distance must therefore be assumed as sufficient to have overcome the total *vis viva* of the ram of 1 ton weight falling 30 feet.

The next point to which he would advert was the attempt to account for the resistance of piles by the friction on their surfaces rather than by their resistance to direct penetration; this friction being estimated at about $\frac{1}{2}$ a ton to the foot superficial in contact with the earth. He thought that although this coefficient might apply to the particular case adduced, no constant coefficient of friction, even for the same material, could possibly apply unless all the circumstances of depth, diameter, and distance asunder of the piles, remained constant. The friction probably increased rapidly as the depth became greater; as each consecutive thickness of material passed through, and displaced by the pile, would have the effect of upheaving pyramidal-shaped masses, increasing in proportion to the difference of the cubes of the depth, or, at any rate, in some large degree with the depth.

From considerations entirely independent of the comparative smoothness of cast iron and timber, he could not agree with the Author as to the friction upon cylinders sunk into the ground, by excavating the material within, affording a proper comparison for the friction of driven piles, as probably the friction upon the latter would be far the greater, in consequence of the driven piles having to displace laterally all the material passed through.

An interesting question, suggested by the foregoing considerations, was the most economical depth to which piles should be driven in a homogeneous resisting material to secure a given sustaining power. It was evident that, *cæteris paribus*, in order to secure an equal amount of bearing power in two systems of piles, driven to different depths, the power absorbed in the two cases would be in proportion to the depth of driving; but the quantity of timber would be increased by using shorter piles, as the numbers would increase in a higher proportion. The question would therefore depend upon the comparative cost of timber and labour.

Sir Charles Fox observed, that no one till now had been bold enough to give a coefficient for the supporting power derived from the frictional surfaces of piles. This might be done perhaps with similar piles driven into similar strata and under similar circumstances; but he would always feel much better satisfied with a crucial experiment in either the effect of a well-observed blow upon a pile, or by loading it with kentledge, inasmuch as various strata

must give very different results, so that a general coefficient might lead to serious errors and misfortunes. He thought some of the observations which had been made led to the conclusion, that the most satisfactory way of driving a pile was to superimpose a larger load than would subsequently come upon it. He was sure if piles were driven to a given limit of resistance by any means, and the supporting power of the piles carefully ascertained, they might be safely loaded nearly to that extent, because, as far as he had ascertained, the sustaining power of piles increased more or less with time, from the tendency there was in the material to settle into a condition of closer contact. He compared the driving of a pile to the driving of a ship's bolt. It was well known that a ship's bolt could be driven into a smaller hole by using two sledge-hammers than by using one only. The reason for which was, he apprehended, that the more rapid succession of blows prevented the fibre of the timber, into which the bolt was being driven, from hugging the bolt to the same extent as it otherwise would do; and so long as it was kept in motion by the more rapid blows, it could be driven into a smaller hole than by using one hammer only, assuming that one hammer took twice the time between each blow that the two would.

Where the object was to render a soil compact which was not firm enough to support a superstructure, he would use parallel piles, because he believed they, as compared with conical ones, were better calculated to make a homogeneous mass. It would, he thought, be apparent, that if conical piles were driven into porous or soft material, the result would be to make the top surface harder than the bottom; and, therefore, to fail in getting a homogeneous and firmer mass. He would also use parallel piles, because they gave a larger bearing surface than conical ones on the solid bottom, inasmuch as 7 inches diameter gave only one-fourth the area of 14 inches, and in that case much of the timber must necessarily be thrown away.

He considered the piles driven in the foundations of London Bridge were worse than thrown away; for if a pile were driven into a soft and plastic material like London clay, and did not reach hard material at the bottom, it could not be called a bearing pile. The act of driving the pile only tempered the clay, and made it still softer, as in that case for every cubic foot of timber driven down, the same amount of clay came up. He believed the subsidence of London Bridge arose from that course having been pursued. The piles which were driven from the up-stream side caused the clay on the down-stream side to be more softened or tempered; hence the settlement of the bridge on the down-stream side. He remembered that twenty years ago there was a fracture through the abutment on the City side of the River, into which he passed his hand; and no

one would, he thought, venture to say that Rennie built the abutment with that nick in it.

Sir JOHN RENNIE, Past President, observed, respecting the pile foundations of London Bridge, that, so far from the clay having been softened or tempered by driving piles into it, the clay became much more consolidated, as was proved by the fact that in proportion as the piles were driven into it, so much more difficult was it found to get them down to their full depth, until the piles last driven would scarcely move with the blow of a ram weighing 15 cwt., falling 25 feet; and so far from the same amount of clay rising up for every cubic foot of timber driven, no rising of the clay was perceptible. If the clay had risen, the piles would have risen also, which they did not do in the least degree.

It was true that the upper surface of the clay between the pile-heads was rendered soft to the depth of from 12 to 15 inches, which was caused by the constant treading of the workmen and the moving about of the pile-engines and stages; but this soft portion was removed down to the solid clay, and the spaces were filled with concrete mixed with stone up to the level of the pile-heads, which were then connected together longitudinally and transversely with cills 12 inches square; the spaces between them were then filled with brickwork, and the whole surface covered with a flooring of plank 6 inches thick, well jointed together and bedded in mortar. So far, therefore, from the piles being worse than useless, they were of the greatest benefit, and without them the foundation would not have been made secure.

He believed, although he could not positively prove it, that the trifling subsidence of the lower end of the piers, was caused by pulling up the cofferdam piles which were directed to be cut off, and by the great scour of the water rushing through the old bridge, also by some error in setting out the work. The trifling subsidence above mentioned occurred in the beginning of the year 1829, nearly forty years ago; since then repeated examinations had been made by accurate levels taken from fixed data, and not the smallest alteration could be discovered. Sir Charles Fox was completely in error in his statement about the crack in the City abutment of the bridge; for there was no crack or subsidence in the abutment, which was founded upon clay with piles driven into it, precisely in the same manner as the piers. The small crack alluded to was in the wing-walls near their junction with the abutment. It was not considered advisable, on account of the great extra expense, to carry them so deep or to pile them to the same extent as the abutment, and in consequence the wall subsidence alluded to took place, which had not altered since the year 1830, when they were finished.

Sir CHARLES FOX considered the object of these meetings was for the purpose of explaining what had been done in the adaptation of

materials to the requirements of the public, speaking not only of successes, but of difficulties encountered, and of blunders committed. To give a homely illustration of the effect of pile driving in soft and plastic material, he would suppose that it was required to erect a structure upon a pound of butter on a plate, and the butter was found too soft to carry the proposed structure: would the butter be stuck full of needles with a view to a better foundation unless their points reached down to the plate? If that were done, the effect would be to knead up the mass, and so make it less able to bear the load than it was before. He had always thought, that if piles were driven into plastic material, and did not reach a firm bottom, the timber was more than wasted; and, in his opinion, it would be much better so to contrive the structure as to bring its weight within the limit of the bearing power of the material on which it was to be placed. Several years ago he had constructed some extensive works on the alluvial soil of the Clyde Valley at Renfrew; before he began he put down a 4-feet square plate of iron, and piled weights upon it till it sank into the sand; and when little more than 15 tons had been put on, the whole began to disappear. Borings were then made, and it was found that the alluvial material went to a depth over 50 feet or 60 feet. He, therefore, contrived that the structure should not press with a weight of more than three-quarters of a ton per superficial foot on any portion of the foundation. The walls, made hollow and light, were placed upon a wide surface of planking, and, though the buildings had been erected more than twenty years, no difficulty whatever had been experienced from the failure of the foundation.

The Author had done good service by stating what weight would move a pile when driven by a certain force; and he thought if engineers, who had the driving of piles under their charge, would occasionally take the trouble to put kentledge on the tops, and test the piling in that way until it began to move downwards, much valuable information would be gained. After sinking the 21-feet cylinders of the railway bridge at Battersea, where he had to join on the masonry of the new to that of the existing bridge, he loaded each of one half of the number of cylinders, with 1,000 tons of kentledge, and each of the other half with 1,200 tons, both of these weights being more than they would possibly have to bear in practice; and nothing could be more satisfactory than the result.

With regard to the plenum and vacuum method of sinking cylinders, in the year 1845 he became acquainted with Dr. Potts, the patentee of the vacuum system. Being pleased with the invention, he resolved to try some experiments with it; and his late firm spent a good deal of money in preparing the apparatus necessary for the purpose. That system was used entirely in the railway bridges at Black Potts, over the River Thames at Windsor, and at Huntingdon,

and partly in the bridge over the River Nene at Peterborough. The success of these experiments led to the intended use of this system under the sanction of the late Sir W. Cubitt, Engineer to the bridge wardens, in constructing the foundations of Rochester Bridge.[1] The drawings of the apparatus were made by Mr. E. A. Cowper, M. Inst. C.E., and the work was most successfully carried on. But Dr. Potts' plan was given up for the following reason:— They had undertaken to put the cylinders into their places at the price of ten guineas per ton, and when 500 tons of them had been delivered, it was found that, instead of having to sink them into loose gravel and sand, as shown by a section of the river supplied, they had to encounter the timber caissons of an old bridge long since swept away, filled with large blocks of Kentish ragstone. It was then that they had recourse to the plenum plan, which was original with them, though he believed they were not the first to suggest its use, Lord Dundonald having long before taken out a patent for making structures under the pressure of condensed air; but they used the plenum plan in sinking 1,700 tons of cylinders at Rochester Bridge with great success.[2] There was a difficulty, to which the Author of the Paper referred, arising from air escaping under the bottom edges of the cylinders while being sunk by the plenum process; that air being forced into the surrounding material, making it loose and spongy, and thereby reducing its hold on the cylinders. Had the Author been aware of the Paper by Mr. Hughes, he would have found that the difficulty spoken of had been encountered, and, as he thought, most satisfactorily dealt with, as would be seen from what was then stated.[3]

The late Mr. Brunel, shortly afterwards, met with difficulties in sinking some of the cylinders for the foundations of the Chepstow Bridge; and having requested that some one should go down with the plenum apparatus to see what was the matter, Mr. Hughes went to Chepstow, and found in one of the deeply-sunk cylinders, in which the difficulty existed, the trunk of a tree lying across and under it. The plenum process being applied, men were sent down, who cut out the tree, and the cylinder was then readily sunk to its proper depth.

The operation of increasing the area of the foundations below the bottom of the cylinders had been carried out with success by Mr. Joseph Cubitt, Vice-President Inst. C.E., in constructing the London, Chatham, and Dover Railway bridge at Blackfriars. He had excavated below the bottom of a cylinder of 18 feet diameter, and so spread out the foundations of concrete to a diameter of 21 feet. With reference also to the use of truncated

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 353.
[2] *Ibid.*, p. 366.
[3] *Ibid.*, p. 358.

cones for increasing the bottom bearing surface of cylinders, he might state that Mr. Hawkshaw, Past President Inst. C.E., had with the best effect adopted that course in putting in the cylinder foundations of the two bridges across the Thames for the South Eastern Railway Company, by which he had doubled the surface upon which they rested on the London clay. He thought it only right to state these things, for people ought not to be allowed to read of and regard as new appliances methods which had been used twenty years previously, and perhaps in a better manner than was represented in the Paper.

Mr. R. P. Brereton said, that twenty years ago Sir Charles Fox and the late Mr. Brunel were the first to introduce largely the use of iron cylinders. Whilst the former was working at Black Potts, the latter was at work at a bridge across the Thames close by. They did not adopt on that occasion the plenum, or the vacuum or Dr. Potts' system, which had been abandoned, there having been no necessity for either process. Dr. Potts' system enabled a vacuum to be got of perhaps 10 lbs. per square inch, or about 13 cwt. per square foot, so that a weight of about 20 tons was the greatest that could be brought to bear upon a 6-feet pile: but this was supplanted, when required, by weighting the pile with 200 tons or 250 tons of iron. Dr. Potts' plan admitted of putting on only very small weights, and it might be useful in sinking piles in situations in sand or out at sea, where iron weights could not be conveniently packed upon the column. He had had considerable experience in driving large and long piles to carry railway structures, especially in Cornwall and in Devonshire, where miles of viaducts had been constructed, many over creeks and rivers with 70 feet to 80 feet depth of mud, where it had been a serious matter to find what kind of foundations were practicable. In the first instance screw-pile iron columns with large blades were tried; but after being carried to a depth of 15 feet or 20 feet, and weighted, they failed and disappeared. After this an attempt was made to reach solid ground by double piles of whole 14-inch timbers bolted together and breaking joint: but the first of these on driving did not reach the bottom, so that that plan was abandoned. Finally the plan was tried of building up large quadrupled piles of whole timbers, with carefully fished butted joints, without any scarfing, and driven steadily with 4-ton monkeys; and in that way numbers of 70-feet and 80-feet piles were successfully driven, without any failure from the starting of the joints or difficulty in driving them. By letting the monkey drop with only a small fall there was no 'besoming' of the timber, or shaking which might have started the butts or fastenings. As it was desirable to keep a pressure upon the pile throughout its whole descent, he had contrived an arrangement of the engine which, by doubling the

weight of monkey upon the pile-head whilst being raised, kept up a constant pressure, and continued to force down the pile during the entire up-stroke, so that when the monkey fell it met with no recoil. As to the formula submitted by the Author of the Paper, assuming that, while driving the piles referred to, he had attempted to calculate what would result from its application when the piles had penetrated to a depth of 30 feet in the ground, it was said that in such a case there was a skin resistance to be expected of 1 ton per superficial foot: therefore in those piles, 2 feet square, the resistance from this cause alone should have been 240 tons, to say nothing of that arising from the bottom of the pile, which had an area of 4 square feet. But these piles were driven down from 25 feet to 30 feet by the weight of the monkey alone; and a resistance of 8 tons only was experienced, when by the formula it should have been 270 tons. This showed to what extent the formula might mislead, although it might apply to the particular places described in the Paper. His experience of pile driving was not confined to two or three places in a creek, but was obtained over considerable distances in the rivers Dart, Tamar, and others. In all cases where there was diluvial clay, these large piles went down 4 feet or 5 feet by their own weight. It was assumed by the formula that the sustaining power of the pile was due to a skin resistance of 1 ton to the foot: and that the effect of lengthening the fall of the ram was to increase the sustaining power in the ratio of the square root of the distance fallen; but that was not compatible with a uniform skin resistance, which increased directly as the distance driven. By carrying the formula yet further, the ultimate sustaining power of the 30-feet pile would be found to be 100 tons, or 1 ton per foot of skin resistance; and that was the basis of the formula. But when the pile was only half driven, and with half the fall of ram, it would have only half the sustaining power by skin resistance, and two-thirds of it by the effect of the monkey driving it in. Formulæ like the one under discussion, though valuable as derived from the Author's experience, and applicable to the particular circumstances met with, must not be made too general.

Mr. Redman referred to a Paper by Mr. Timperley, on the Harbour and Docks at Kingston-upon-Hull, where, in an account of the construction of the Junction Dock, it was stated that the greatest insistent weight upon a nest of piles supporting the foundations of the swing-bridge over the lock, amounted to 20 tons on each pile of whole timbers 16 feet in length.[1] In reference to the two processes for sinking cylinders, the vacuum and the plenum, the first was applied by Dr. Potts, and a patent

[1] *The* Transactions Inst. C.E., vol. i., p. 34.

taken out for it twenty-five years ago: but it was at a period when Mr. Redman was sinking cylinders by the open well system in the lower reaches of the River Thames, and those works were visited by the Patentee before registration. An instance of failure of that process had been given by Mr. Hemans, and he might now mention a successful application of it, as the Corporation of the Trinity House, at the instance of the late Duke of Wellington, about twenty years back, employed that process under circumstances favourable in one respect, inasmuch as the soil was a quicksand, but disadvantageous in another, for the site was in an open seaway. The object was to ascertain the level of the chalk substratum beneath the Goodwin Sands. No means were adopted for guiding the cylinders by a fixed stage as he had advised, and they consequently took an oblique direction, which might, however, have been readily obviated, the only tackle used being from lighters. The cylinders were sunk through the Goodwin Sands, and reached the chalk at a depth of about 50 feet below low water; and they were subsequently used for the foundation of a beacon. The difficulty of sinking by Dr. Potts' process arose from its powerful suction on the quicksand, which displaced so much more material than was due to the cubical capacity of the mass inserted, that the soil around was loosened, causing a tendency to diverge from the perpendicular. The 'plenum' process was entirely French in origin, and earlier than the 'vacuum,' and would be found minutely described in the Supplement to Dr. Ure's 'Dictionary of Arts, Manufactures, and Mines,' under the Article 'Ventilation' (date 1845), in which there was an account of its application several years before by French engineers to penetrate a semi-fluid quicksand in the Loire district, in direct communication with the waters of the Loire. A wrought-iron cylinder, with an air-lock at the top for passing the labourers and tackle through, was charged with dense air and converted into a diving-bell, and sunk between 60 and 70 feet (22 mètres) through this sand to the coal-seam beneath, supposed hitherto to be unattainable. He thought the value given by the Author for frictional skin resistance, in reference to piles and cylinders, was too high. On one occasion he sunk a cylinder, 6 feet in diameter, through a thickness of 14 feet of alluvial sand and gravel, in the lower district of the Thames, to the solid chalk. The cylinder excluded the flow of the tide. It was got down with some difficulty, required to be heavily weighted, and a brick invert was put in. It was left at night without making the usual provision for the admission of the rising tide: and a high tide occurring, the water rose within a few inches of the top. When the men went down to resume work in the morning, it was found that the invert had been partially forced into a dome shape, and that the cylinder had been floated, like a bottle,

3 feet, by the tidal pressure penetrating through 12 feet or 14 feet of material: a column of water in effect of 30 feet acting on the area of a 6-feet cylinder, as opposed to 14 feet in height of circumferential resistance. According to the figures given by the Author such a result was impossible, but such was the fact. It was curious to note that the first practical application of the 'plenum' process to wrought-iron cylinders, with an air-lock passage at the summit by the French, was coincident with the enrolment of Dr. Potts' patent for the 'vacuum' process, its successor, and not predecessor, as assumed; and he might refer to the fact, that although the application of iron cylinders for foundations was well understood, and exceeded by subsequent examples, the cast-iron cylinders sunk by him for the foundations of the pier at Milton-on-Thames, opposite Tilbury Fort, a quarter of a century back, were in reality the pioneers of the system. A French Government Commission visited that work soon after its completion, and by permission of the Directors measured all the details.

Mr. A. Beazeley observed, that in the formula the Author had omitted to take into consideration one important element connected with pile driving, the effect of the blow of the ram upon the pile. He had made some numerical calculations which told upon the proposed formula as applicable to practical matters. On comparing it in connection with work he had done, he found that it gave a bearing power far short of what ought to be expected, and much inferior to that given by the formulæ of Weisbach and Rankine, even without the reduction of each to the limit of safety, which still further increased the difference. In one case, where Rankine's formula showed a bearing power of 112 tons, and that of Weisbach 128 tons, the formula, given by the Author, showed a supporting power of only 59 tons. When such a difference was found, it might fairly be assumed that the error lay with that formula which omitted to take into account the important element of the effect of the blow upon the pile. The Author spoke of driving a pile to the point of ultimate resistance, and that was mentioned as diminishing from 8 inches to nothing; but it was known that, if a pile was driven till it absolutely refused to go any further with the blow of one ton from a ram falling 30 feet, the weight of 125 tons afterwards applied to it could not stir it, as it must have reached some impenetrable material; and, therefore, under any circumstances the formula would be inapplicable, because the effect of the ram on the pile had been really in no case taken into consideration.

He thought that for practical purposes there was not a better formula than that of Major Sanders of the United States Engineers,[1]

[1] *Vide* Journal of the Franklin Institute. Third Series, vol. xxii., p. 304.

viz., $W = \frac{R F}{S D}$, where W = the weight that can safely be placed on a pile, R = weight of ram, F = fall of the ram in making the last blow, and D = the distance the pile sinks with that blow. Comparing the results obtained, and taking as an example the pile-

CUDGEGONG BRIDGE, MUDGEE. (MARCH, 1859.)

SUPPORTING POWER of PILES, as estimated by various Formulæ.

No. of Pile.	Depth in Ground.	Total Length of Pile (L).	Value of P = L × ·022.	Value of D.	Value of F.	Values of W in Tons and Decimals. Sanders, $\frac{FR}{8D}$	Rankine, $\sqrt{\frac{4ESRF}{L} + \frac{4E^2S^2D^2}{L^2}} - \frac{2ESD}{L}$	Weisbach, $\frac{F^2F}{(R+P)D}$	M'Alpine, $\frac{80(R+0\cdot22^2\sqrt{F-1})}{10}$
	Feet.	Feet.	Ton.	Foot.	Feet.				
1	15·	20·	·440	·0573	10·58	23·09	111·68	128·22	5·93
2	13·	18·	·396	·1094	11·83	13·52	87·03	77·75	6·27
3	12·	17·	·374	·0833	10·	15·	91·41	87·72	5·77
4	12·5	17·5	·385	·0833	10·5	15·75	94·52	91·34	5·91
5	13·25	24·75	·544	·0313	10·	40·	122·04	206·93	5·77
6	13·	24·75	·544	·0677	11·5	21·23	103·79	109·53	6·19
7	13·67	25·17	·554	·0885	10·	14·12	81·37	72·71	5·77
8	16·	27·5	·605	·0573	10·	21·82	97·69	109·31	5·77
9	15·58	26·33	·579	·0625	10·	20·	95·52	101·33	5·77
10	16·	27·	·594	·0625	10·	20·	94·82	100·38	5·77
11	16·75	27·5	·605	·0625	10·	20·	94·33	99·69	5·77
12	17·5	28·25	·622	·0469	10·	26·67	103·97	131·45	5·77
13	14·67	24·17	·532	·0729	10·	17·14	91·05	89·42	5·77
14	13·5	23·5	·517	·0833	10·	15·	85·47	79·14	5·77
15	17·67	26·17	·576	·0678	10·	18·46	92·31	93·71	5·77
16	17·25	25·75	·567	·0573	8·	17·45	85·06	89·11	5·16
17	18·25	23·75	·522	·0781	10·	16·	88·28	84·09	5·77
18	18·67	24·17	·532	·0833	10·	15·	84·93	78·33	5·77
19	14·92	20·42	·449	·0833	10·	15·	88·16	82·82	5·77
20	16·25	21·75	·479	·0729	10·	17·14	93·45	92·72	5·77
					Mean	19·12	99·34	100·28	5·80
					Ratio	1·00	5·20	5·24	0·30

W = Safe load on pile for Sanders and M'Alpine; = theoretical load for Rankine and Weisbach.
F = Fall of ram in making the last blow.
D = Distance the pile sinks with last blow.
R = Weight of ram = 1 ton (constant).
L = Total length of pile.
P = Weight of pile.
S = Sectional area of pile = 0·7 foot (constant).
E = Modulus of elasticity for slaty-gum timber = 331,100 inch-pounds (constant).

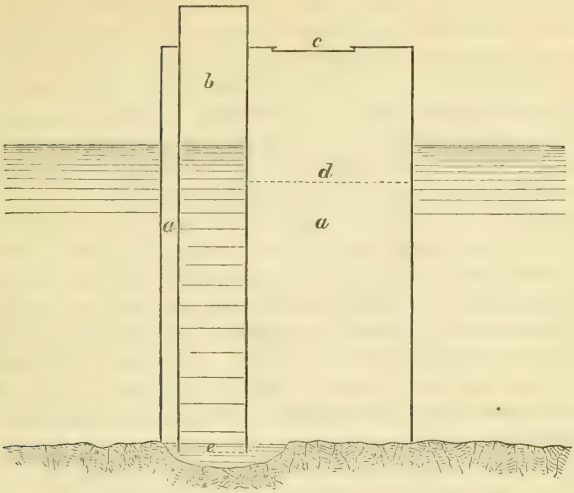
driving of one complete work from actual practice, he found that the average supporting power of the piles, as calculated by Rankine's formula, was 5·20 times, by Weisbach's 5·24 times, and by that proposed by the Author 0·303 time that given by Sanders'. But Rankine stated that the load to be placed on a pile when it was driven to the test should be from one-third to one-tenth, which would amount, on an average, very nearly to dividing his absolute results by the ratio 5·20. Weisbach stated that the load should vary from one-tenth to one-hundredth, but that appeared to be beyond all reason, and, as his absolute result tallied so closely with Rankine's, the ratio 5·24 might fairly be taken as a divisor. The Author stated positively one-tenth as the ratio where there was any exposure to vibration. The result was, that Rankine's and Weisbach's formulæ practically agreed with Sanders's, while the one now proposed indicated an average uniformly too low, being only 0·303 of the other results.

Mr. John Wright said, as a matter of history with regard to the plenum apparatus, that the facts were not exactly in accordance with what had been stated. When it was resolved to sink the piles for Rochester Bridge by Dr. Potts' system, Sir W. Cubitt requested him to go to Huntingdon to examine the effect on piles sunk by that system; but he found its effect on the cylinders so unsatisfactory, that he could not advise its adoption at Rochester Bridge. It then occurred to him that the better plan would be to reverse the process, to drive the air into the cylinders, put the men inside, and excavate from the bottom. This plan (Fig. 1) was submitted to Sir W. Cubitt, who arranged for its adoption.

This plan was never carried out, because Mr. Hughes introduced the air-lock at this time, and a more satisfactory system could not be imagined, as, during the whole period it was in use, there was never any loss of time from the apparatus getting out of order.

Lord Cochrane's name had been mentioned in connection with this system. If his lordship had been at Rochester, and had taken an account of all that had been done there, he would have found that the troubles they met with were provided for in his specification. Therefore they took no credit to themselves as the Authors of the plenum apparatus, although ignorant at the time of Lord Cochrane's patent. He thought the plenum process was an agent that might be used to a much greater extent in building foundations under water at any reasonable depth, and then to erect solid masses of masonry without leaving any iron in the place, and preserve the bond to any extent. He had not yet carried out that plan practically, but he hoped before long to do so, when he would communicate the results to the Institution.

Fig. 1.



a, *a*, cylinder.
b, a tube, say 2 feet in diameter.
c, man-hole.
d, stage inside the cylinder for men to stand on until the cylinder was clear.
e, sump, always kept below the bottom of the tube. Buckets were to be lowered down through the water in the tube, drawn out through the sump by the men excavating at the bottom, loaded and passed through the sump, drawn up through the water in the tube, and the contents discharged without any loss of air, as in the lock system.

Mr. BRUNLEES noticed that, in the formula given by the Author, the energy of the blow was taken to be proportional to the velocity of the ram, *i.e.*, the square root of the fall. He did not consider this formula so reliable as that set forth by Professor Rankine,[1] who took the energy as proportional to the fall. In the latter case the work done was taken as the data, whereas in the former the work done was assumed.

It was, however, well known to all experienced in pile-driving, that there were many kinds of material so elastic that the pile sprang up again after a blow to the point from which it was struck, and no kind of formula could possibly meet a case like that.

The Author, in dealing with iron piling, relied principally upon the supporting power derived from the frictional surface; but he, on the contrary, in all alluvial and sandy soils, sought to obtain a direct bearing surface, as in the screw and the disc pile.

Instead of a single cylinder, he had used, for spans over 60 feet, a cluster of piles, as shown in Fig. F., Plate 13, varying in dia-

[1] *Vide* "A Manual of Civil Engineering," pp. 603, 604.

meter according to the span. Those shown in Fig. F, were 18 inches diameter, as used for spans of 111 feet in the Eau Brink Viaduct near Lynn; the screw was 3 feet 3 inches in diameter. Therefore the bearing surface for each pile was 8·3 square feet, or for five, the number under each girder, 41·5 square feet. The metal in the five piles was equal to that of a cylinder of 4 feet 4 inches diameter, or a base of 14·2 square feet. Consequently he obtained three times the bearing with the same metal, without taking into account the concrete or masonry required to perfect the cylinder, none of which was required in the piles. The cost of screwing the Eau Brink piles was 12*s.* per lineal foot. The process of screwing was much simpler than that of sinking by the pneumatic process, and, although he had no means of comparing the cost, he had no hesitation in saying that screwing, where practicable, not only gave the safest, but also the least expensive bearing. All the parts were light to handle, and the men worked in the free air and above water.

In the various kinds of material in which he had used piles, the following forms had been adopted.

For fine sands, such as were met with in piling for the Morecambe Bay Viaducts and Southport Pier, the disc form, Fig. A, was used. The piles at the former place were sunk by force pumps, worked by a two-horse steam engine, and at the latter by the head of water on the town mains. In both these cases the force of water removed the sand from under the disc, and the piles were gradually lowered as the sand was forced upwards. In Morecambe Bay the cost was 2*s.* 6*d.* per foot sunk, and at Southport only 4½*d.*, so great was the advantage of using the pressure of the town water. At Southport twelve piles were repeatedly put down in a tide, while at Morecambe the average was scarcely two in a tide.

In the extension of Southport Pier, now nearly completed, the form Fig. B had been successfully used. The serrated ribs were introduced to take the place of the cutters shown in Fig. A, for the purpose of scraping through hard bands of deposit occasionally met with in the sands. The power for sinking these was obtained from two ordinary fire engines.

For hard gravel shale and soft rock, such as were met with in the piers on the River Mersey, he had adopted the corkscrew form, Fig. D.

In all alluvial deposits, both at home and abroad, he had used the ordinary-bladed screw-pile, Fig. C. Out of seventeen river crossings in Brazil, fifteen were on these piles. In one case he used them for ten spans in a depth of from 35 to 40 feet of water with perfect success.

In the Solway Viaduct, which was more than 1 mile in length, it was originally intended to use the screw-pile, but on trial it was found, after getting through a depth of about 4 feet of sand,

A
B
C
D
E
F
G
inches 12 6 0 1 2 3 4
inches 0 1 2 3 4

that there was such an exceedingly hard stratum of gravel bound with stiff clay beneath, that the screws would not enter, and the form Fig. E was adopted. The driving of these was just completed. No experiment had yet been made on their bearing powers, but, according to the formula of Professor Rankine, taking the ram at $1\frac{1}{4}$ ton, the fall at 4 feet, and the distance driven by the last blow at $\frac{3}{8}$ inch, after deducting the absorption of power by the use of a timber dolly 10 feet in length, the bearing power ought to be equal to 122 tons per pile. The driving of these piles cost 2*s*. $10\frac{3}{4}$*d*. per lineal foot, or, including wear and tear of pontoons, piling machinery, &c., 4*s*. 6*d*. per lineal foot. The steam machinery used was made by Sissons and White. The time available for working at low water averaged only three hours, and in that time three piles were generally got down.

In sinking timber piles in sand, for forming such works as fenders for drawbridges, the form Fig. G had been used. These were sunk by the agency of water in the same way as the ordinary disc piles.

The worst bearing material with which he had to deal was that in Morecambe Bay; and, so far as experiments were tried, they proved that there was no difference in the bearing power at a few feet, and at 20 feet under the surface. He accounted for this from the fact of the proximity of headlands, the pressure from which formed soaks and springs in the bays, thus keeping the sand in a semi-fluid or quick state. The bearing power of these sands after repeated experiments was found to be 5 tons per square foot of disc. It was also found that time did not increase the bearing power, as piles tested after being down three months yielded to the same weight as at first.

He believed that, for iron viaducts, there were no foundations so weak that piles might not be adapted to them, provided the spans were kept within moderate limits, and the piles were small and numerous, so as to diffuse the load.

Of the various kinds of piles shown on Plate 13 he had used over three thousand, and, so far, not one had sunk or failed. Still he had no hesitation in saying that Mitchell's screw-pile was most generally useful for all kinds of material, excepting pure sand, for which he preferred the disc.

Mr. T. D. Ridley had long been in search of a formula for comparing a statical load with a dynamical force. He had grave doubts as to the applicability of the formula set forth by the Author, and should have been better satisfied had he given fuller details of his experiments. The equation, as he understood it, meant this:—that on one side there was a ram, whose weight was known, falling from a given height, and by its impact exactly balancing the forces opposing the descent of the pile upon whose

head it fell, so that no motion was produced, but only a state of things bordering upon motion; and on the other side a dead weight resting upon the head of the pile, and producing the same result. Hence the equality. He should like to know what space of time was occupied in loading the lever, by means of which the testing weight was applied to the head of the pile; also how far the pile settled when the ultimate load was reached or exceeded; likewise what further increase of load produced further motion, and to what extent. It would be observed from the equation, that the effective force of the blow was in proportion, not to the work which had been done upon the hammer, but to the square root of the height to which it had been raised; in other words, it was proportional to the velocity of the hammer at the moment of concussion. He, however, questioned the fact that the useful effect of the blow was in proportion to the velocity of the ram, because, when the velocity was great, the momentum doubtless was also great, but with a high velocity the instant of concussion during which the ram transmitted its momentum was so transient, that much of the useful force of the blow was lost, being absorbed by the pile itself, which had, as it were, not time to convey it to the resisting media into which it was being driven. This might be exemplified by the effects produced by projectiles travelling at comparatively high and comparatively low velocities.

He utterly deprecated the use of blows with a ram falling from a height of 30 feet, or anything approaching it. In ground easy of penetration there could be no occasion for such a fall, and in difficult ground such a height of fall would only destroy the pile, which, if it did not fail at its head, or fracture, would be broken or bruised at its point, and would cease to penetrate the ground, although the descent of the head might indicate apparent advance. Eleven years ago he drove a large number of piles for the foundations of the viaduct which carried the Border Counties Railway across the River Tyne at Hexham. Mr. J. F. Tone, of Newcastle-upon-Tyne, was the Company's Engineer, and he had charge of the works. The bed of the river consisted of compact boulder gravel and sand, which latter material, when it contained water and had a superincumbent load, was perhaps the most difficult substance through which it was practicable to drive piles. After the first few blows, none of the piles descended more than three-eighths of an inch for each stroke of the ram, and at depths ranging, according to situation, from 16 feet to 33 feet, they responded only one-eighth of an inch to the final falls of the hammer. Rams weighing 20 cwt. and 24 cwt. were found to be of little use in this case, and the piles usually failed under the high fall of 16 feet to 20 feet, which was required to force them downwards. Seeing the injurious effects of using a light hammer with a long stroke, he resorted to rams weighing 50 cwt. each, and by giving them a fall of from 8 feet to

12 feet, and never exceeding the latter limit, the piles were successfully driven. The conclusions there formed, as to the superiority of a heavy hammer with a low fall over a light ram with a long stroke in difficult ground, had been amply confirmed by subsequent experience, more especially that derived from the construction of the coffer-dams for contract No. 2 of the Thames Embankment.

Mr. G. J. Morrison observed, through the Secretary, that when a pile had been driven into the ground it would bear a certain weight without sinking; in other words, it resisted being pushed into the ground with a certain force. Let this force be called P. When a pile was driven by a blow of the ram, the amount of work done was the force or weight P moved through the distance the pile was driven. Let this distance be called x: then Px represents the work done in driving the pile. Now x was known, and consequently P could be ascertained, if the amount of the work expended in driving the pile be discovered, and that amount be divided by x.

When a ram fell the mechanical energy of the blow was expressed by the weight of the ram (W), multiplied by the distance through which it had fallen (h). If the whole of this energy were used in driving the pile, then would $P x = W h$, and $P = \frac{W h}{x}$. But the blow did more than drive the pile.

In Rankine's formula[1] the expression $\frac{P^2 l}{4ES}$, representing the amount of the blow expended in compressing the pile, would be better written $\frac{P^2}{2ES} \times D$, where D was the total length of the pile out of the ground + half the total length of the pile in the ground: but what he particularly wished to call attention to was the fact that this member did not involve W, h, or x. This signified that the amount of work done in compressing the pile was the same for any strength of blow, provided that the blow was sufficient to move the pile by an amount however small. The same would be the case with the elasticity of the ground. Let the work used in overcoming this be called M. The formula will then be

$$W h = P x + \frac{P^2 l}{4ES} + M.$$

Let a blow be given from the ram falling a distance h, and let it drive the pile a distance x; then let a blow be given by the ram falling a much greater distance h_1, and let the distance the pile was driven be represented by x_1.

[1] *Vide* "A Manual of Civil Engineering," p. 604.

Then in the one case, $W h = P x + \frac{P^2 l}{4 E S} + M$,

and in the other, $W h_1 = P x_1 + \frac{P^2 l}{4 E S} + M$;

subtracting one from the other, $W (h_1 - h) = P (x_1 - x)$,

and, $$P = \frac{W (h_1 - h)}{x_1 - x}.$$

Hence, to ascertain the supporting power of a pile, first find the amount it could be driven by a blow of a ram falling a certain distance, then the amount it could be driven by the same ram falling a greater distance; next multiply the weight of the ram by the difference of the two falls, and divide it by the difference of the amounts driven in each case, and the result would be the sustaining power. The mean of a few blows could be taken in each case, as practically the sustaining power would be constant for several inches. He believed that, except in very springy soil, this would give a result very near the truth.

Mr. G. B. Bruce was of opinion that no formula or calculation of any kind would give the smallest approach to certainty in endeavouring to arrive at the facts as to how a pile would be affected under supposed circumstances. He thought that nothing but actually pitching a pile and driving it would afford accurate conclusions. He also thought it impossible to ascertain what dead load a pile would bear from knowing the distance it was moved by a given weight of ram and a given fall.

Mr. J. M. Heppel had some years ago instituted experiments with the view of ascertaining the amount of pressure to which the head of a pile was actually exposed during the process of driving.

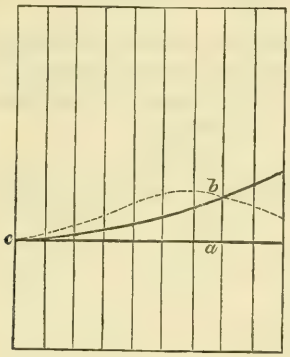
It was plain that if an exact register of the motion of the ram could be obtained, that was to say its exact position at given minute intervals of time; the force which must have been acting upon it at each moment would be a direct conclusion from the first principles of dynamics. It was such a register that he tried to obtain.

A piece of drawing-paper was stretched on a board, and a pencil attached to a strong spring fixed to an independent support, and having sufficient range when let go to draw a horizontal line completely across the paper, which was divided by vertical lines into equal spaces: a detent held back the spring, and was capable of being released at the time when the board descending vertically passed a certain point.

To ascertain at what intervals of time the pencil, in drawing a horizontal line by the action of the spring, passed the several vertical lines, the board was fixed in a vertical slide, so that it

might have a fall of 3 feet or 4 feet; and the spring was fixed opposite to it, so that on reaching a certain point it released the detent. It was then first moved slowly down to this point till it touched the detent, and the pencil drew a horizontal line. Next it was allowed to drop through a given distance, and on passing the same point, it now had a known velocity, which for the small interval taken up in observing the line might be regarded as uniform. This velocity being compounded with that of the spring, the line drawn was no longer horizontal, but deviated from that direction in a certain curve. The interval of time which the board took in falling through any vertical distance, Fig. 2, was ascertained from its known velocity; and as the pencil passed a certain horizontal distance in the same time, the times of its passing all the vertical lines became known. The instrument was now prepared for use.

Fig. 2.



In making an experiment the board was fixed to the pile near its head. The spring and pencil were fixed to an independent support, and the detent was so adjusted as to be released the moment the slightest motion in the pile took place.

A curved line was thus drawn; and the times at which the pencil must have arrived at each of the vertical lines being already known, the times at which the head of the pile was at the level of their intersections with the curve became known; and the motion of the ram being taken as the same as that of the pile-head, which it would be, at any rate, up to the point of maximum pressure, which was the point most essential to ascertain, the velocity of the latter at any instant could be computed, and consequently the force to which it must at that instant have been subjected. He thought that a correct estimate of the actual maximum pressure exerted was obtained by this means: but how far this should be considered indicative of the amount of permanent load to be safely carried by the pile was a matter of judgment.

A simpler method, founded on a similar principle, would probably give an approximate indication of the bearing power.

The pile having been driven to the required depth, let it be ascertained by trial what the greatest height was from which the ram might be allowed to fall on it without either driving it or impairing its elasticity. The pile would then at every blow be compressed to a certain extent, and would recover its original dimensions :—

Call the weight so ascertained	H
The weight of ram	W
Length of pile	L
Sectional area of ditto	K
Modulus of elasticity of ditto	E

and call the amount of compression of the pile at any instant x.

Then $\frac{E K}{L} \times x$ would be the force of compression at that instant; and when the motion of the ram was destroyed the compression would have reached its greatest amount. Let this be called X, and the pressure on the pile would be the greatest. Call this P.

Then from equality of work—

$$W H = \frac{E K}{L} \times \int_0^X x \, d x = \frac{E K}{2 L} X^2.$$

But, $$P = \frac{E K}{L} \times X;$$

$$\therefore X^2 = \frac{L^2}{E^2 K^2} P^2$$

and $$W H = \frac{L}{2 E K} P^2,$$

and $$P = \sqrt{\frac{2 E K W H}{L}}.$$

The above expression was independent of any particular system of measures or weights; only requiring that P, W, and E be taken in the same units of weight; H and L in the same unit of length, and that E should apply to the unit of area in which K was taken. As an example, suppose a pile of fir timber 1 foot square, and 50 feet long, would bear a ton monkey dropping 2 feet, without driving any further or losing its elasticity. Taking E in tons per square inch at 660, then

$$P = \sqrt{\frac{2 \times 660 \times 144 \times 1 \times 2}{50}} = 87 \text{ tons.}$$

It would be observed that this supposed the resistance to be concentrated at the toe of the pile; but a little consideration would show that, if applied at any other point, or distributed over its surface, its amount must have been greater, because the range of motion must have been less. He, therefore, thought that the above was a reliable estimate of the least possible value of the maximum pressure to which the pile could have been subjected.

The subject of impact and pile driving was fully investigated in "Moseley's Principles of Engineering,"[1] but the expressions were so complex as to be of little practical use, though they might be made so by tabulating the results. Moseley's final equation was insoluble with respect to P; but putting P = 87 tons, as in the above example, and leaving the other conditions the same, it gave for the distance driven —0·0001 foot, which agreed very closely with the above where that distance was taken to be nothing.

The formula given above was immediately deducible from Moseley's equation 726 by putting the first side = 0, and expunging from the other side quantities which were insignificant compared with the others. It thus became

$$0 = V^2 - g \times \frac{L}{K E} \times \frac{P^2}{W},$$

from which the other followed at once, since $V^2 = 2 g H$.

Mr. W. Eckersley had, in conjunction with the Messrs. Waring, constructed the viaducts over the Eau Brink Cut at King's Lynn, and across the Solway, and could corroborate the figures given by Mr. Brunlees as to the cost of screwing piles at the former place, and of driving piles at the latter.

The viaduct at the Eau Brink Cut carried the single line of the Lynn and Sutton Bridge Railway over the river called the Eau Brink Cut. The piles were 18 inches in diameter, with a screw of 3 feet 3 inches in diameter, and were screwed into position from a fixed staging in the usual manner, viz., by capstan bars of timber fixed into a disc clamped tight to the pile. The power was applied by two double purchase crabs; ropes being passed round the capstan bars in connection with these crabs. Six men worked at each crab, four in winding, and two hauling in the slack of the rope. The material passed through in two of the deep piers had a thickness of 7 feet of clay and marl, 2 feet of hard gravel, and 9 feet of strong clay, giving a total depth of 18 feet to which these piles were screwed. The average rate of progress, after a pile had been pitched into proper position, was 8 lineal feet per day. The cost of labour only was 6*s.* 6*d.* per lineal foot; that of plant, staging, &c., &c., 5*s.* 6*d.*; or a total of 12*s.* per lineal foot. The net

[1] *Vide* "The Mechanical Principles of Engineering and Architecture," p. 598.

cost of each foot of pier, each pier consisting of a cluster of ten piles, or, rather, of two clusters of five piles each, including cost of iron and all other matters, was £10. 5*s.*; and the cost of the temporary staging was equal to 28*s.* per ton spread over the cast and wrought-iron work. The net cost of the viaduct was £22. 7*s.* per lineal foot; and when it was borne in mind that the four piers reached a depth, on the average, of 60 feet, this must be considered a cheap structure. The two piers in the main channel of the river were 75 feet deep, and the two piers at the sides of the river 45 feet deep from the top of the pier to the bottom of the screw, being an average of 60 feet for each pier. He considered this mode of constructing piers of screw piles in clusters very suitable for such rivers as that at King's Lynn, where there was a strong flow of water, and great oscillation of tide. It possessed the merits both of simplicity and economy.

At the Solway Viaduct twelve hundred and twenty-four piles had been driven. They were of cast iron 12 inches in diameter, and, with the exception of fifty or sixty, were driven from pontoons. The cost of the Solway Viaduct, 4*s.* 6*d.* per lineal foot, might seem a high price, but great losses sustained in heavy storms of pontoons and plant had added materially to the cost. The labour in driving cost only 9½*d.* per foot; the remainder being due to the cost of loading and unloading material, use of steamer, proportion of salaries to engineers, foremen, and others, and the use and repair of the plant. A pile 20 feet in length, after being pitched into position, was generally driven down 18 feet or 19 feet in thirty minutes, having received from twelve to fifteen blows per minute from a monkey or ram weighing 25 cwt., and with a drop of 5 feet. A timber dolly was used between the pile and the ram, with a copper ring between the shoe of the dolly and the pile head. Six piles were usually driven in two tides. About twenty experimental corkscrew piles were got down to a depth of 8 feet or 9 feet by horse power, and at a cost of 3*s.* 6*d.* per lineal foot. Four levers of oak, bound round with hoop iron, each lever being 24 feet long, were fitted into a disc on the pile, and the horses worked at the end of the lever. By this plan a pile was screwed down 8 feet or 9 feet in two hours. The material encountered was, however, so very hard, that it was finally decided to drive the piles. This experiment showed that horse power could be effectually employed, where the sands of an estuary or side of a tidal river were dry at low water, in screwing piles, and it was a method that possessed many advantages.

A simple and efficient plan for screwing down piles in stiff material had been adopted at certain bridges now in course of construction by Messrs. Eckersley and Bayliss on the Bath and Mangotsfield line of railway. These bridges crossed the River Avon, and were designed by Mr. J. S. Crossley, of Derby, for the Midland

Railway Company. Messrs. Handyside & Co. of Derby had executed the ironwork, and the plan of screwing referred to was invented by them. The piles were 2 feet 6 inches in diameter, with a screw of 4 feet 9 inches diameter; and they had been screwed into place from fixed staging by the machine referred to, which consisted of a solid cast-iron hexagonal shaft, bolted on to the head of the pile to be screwed down; and this shaft was passed through the centre of a cast-iron wheel 5 feet in diameter, a sufficient space being left between the sides of the shaft and the sides of the opening in the centre of the wheel to allow for the gradual sinking of the pile. Teeth similar to those of a mitre wheel were placed on the outer rim of this wheel; in fact, it was a worm wheel, worked by a worm-screw fixed on a shaft, which shaft was turned by handles very much like a common winch. At some of these bridges beds of thin, shaley rock were met with, and were cut through by having a piece of pile 9 inches long cast on below the screw; this piece was cast with saw teeth at the bottom and with sharp ribs up its length, and these acted as cutters. By this plan rock of considerable hardness could be cut through; and if it were sufficiently compact, a hole 9 inches in depth, and 18 inches in diameter was made, which formed a capital seat for the foot of the pile, and helped to keep it in position, the bottom of the screw resting on the top of the rock. This screwing machinery cost about £110, and he considered it had answered its purpose remarkably well.

February 25, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper No. 1,187, "On the Supporting Power of Piles, &c.," by Mr. McAlpine, occupied the whole evening.

March 3, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—William Douglass, Lieut.-Colonel John Pitt Kennedy, Richard Laybourne, William Henry Edward Napier, and Josiah Timmis Smith, as Members; James Binfield Bird, William Gammon, Thomas Bland Garland, William Hunt, James Trubshaw Johnson, Lieut.-Colonel William Lawtie Morrison, R.E., Patrick Ogilvie, Robert Sabine, James Shaw, Samuel Swarbrick, and Albert Vickers, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-laws, as Students of the Institution:—Benjamin Hall Blyth, M.A., Alfred George Brookes, Richard Ernest Brounger, William Augustus Kennedy Gostling, Arthur Henry Heath, Charles Assheton Whately Pownall, Percy Frederick Tarbutt, and Frederick Toplis.

No. 1,196.—"The Manufacture and Wear of Rails."[1] By Christer Peter Sandberg, Assoc. Inst. C.E.

In these times, when communication is carried on chiefly by means of railways, it becomes important to determine the best mode of manufacturing railway bars, so as to obtain the greatest amount of wear with the least possible cost. As this question is one of increasing interest, the Author has thought that it might be profitable to communicate to the members of The Institution of Civil Engineers, the experience which he has gained, during the last nine or ten years, whilst engaged in superintending the supply of rails for the Governments of Sweden, Norway, and Denmark.

The Paper will treat; first, of the best method of manufacturing rails out of common iron, and of their capacity to resist wear; secondly, of the disposal of the iron rails when they are worn out; and thirdly, of the conditions under which either iron or steel, or a combination of both, may be the most economical material for the construction of rails.

The mode of manufacturing rails for the Swedish Railways, as carried out in Wales, between the years 1856 and 1860, consisted

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

in hammering the pile for the top slab after the first welding heat, and in rolling it after the second heat. It was supposed that hammering would produce a superior weld and a harder wearing surface than could be obtained by rolling alone. This method of hammering was, however, gradually superseded by that of rolling at other works in Wales, during the period referred to. As the operation of hammering the slab after the first welding heat entailed an additional charge of 20*s.* per ton, it became the duty of the Swedish Government to determine, by practical trials, whether the value of the finished rail was correspondingly increased. With this view, several experimental rails were rolled, and arrangements were made for putting them down on some of the English lines, in such situations as would expose them to severe wear. The experiments further aimed at discovering, if possible, how long the rails manufactured at the Cwm Avon Works, in South Wales, and imported into Sweden, would resist the traffic in that country.

Five different kinds of 'piles' were employed; twenty rails, of a flange section, 4½ inches deep, and weighing 62 lbs. per yard, being rolled of each particular sort.

The mode of manufacture was as follows (Plate 14):—

The rails subsequently noticed in this Paper as those marked **T** were made from a pile formed of No. 2, or welded iron, for the top and bottom, the rest of the pile being of No. 1 puddled bar iron. The top slab and the squares next to it were made from a hammered bloom of ordinary puddled bars, and the remainder was filled in at the middle with crop ends from top slabs, and with other pieces of No. 2 iron.

The rails marked **Y** were made from a pile of the same composition as that of the **T** rails, with the sole difference that the pile for the top slab consisted of puddled bars, without any welded iron pieces or crop ends being introduced in the middle of the pile.

The pile for the rails marked **H** was composed of a top slab made from puddled bars, hammered after the first heat, and rolled after the second heat, similar to the rails marked **Y**, the iron for the flange consisting of four pieces instead of eight.

The pile for the rails marked **E** was exactly similar to that for the rails marked **H**, excepting only that the pile for the top slabs was rolled after the first heat, as well as after the second heat. This difference in the mode of manufacture was adopted in order to discover whether the process of hammering when applied to this common iron improved the rail to a corresponding extent. Instead of No. 2 iron, puddled bars were chiefly used for the squares near the slab, and for the foot of the rail.

The pile for the rails marked **N** consisted of puddled bars, without any top slab.

All the piles passed through the rolling successfully, with the

exception of the N rails, some of which showed cracks, owing to the inferior quality of the puddled bar.

The London and North Western Railway Company, being interested in the solution of this problem, allowed experiments to be made on their line, so far as the wear of these experimental rails was concerned. The experiments were carried out at Camden Town Station, where the rails could be sooner and more thoroughly tried than elsewhere; first, on account of the enormous traffic which obtains at that spot, secondly, from the constant shunting, and, thirdly, owing to the grinding action of the engine wheels in starting the trains. The result of these experiments is shown in a series of tables, drawn up by Mr. H. Woodhouse, Superintendent of Permanent Way. (*Vide* Appendix, page 334.)

The following Table, deduced from Mr. Woodhouse's report, shows the number of tons passed over each kind of experimental rail before it was crushed, and also before the rails were taken out.

Mark of Rail.	Crushed.	Worn out.
	Tons.	Tons.
T . . .	3,680,000	5,060,000
Y . . .	4,140,000	5,290,000
H . . .	3,220,000	5,060,000
E . . .	6,900,000	8,970,000
N . . .	3,220,000	5,520,000

Another Table, calculated from the preceding one, shows how long the rails will last, supposing them to be passed over by three thousand trains yearly, each train being composed of an engine weighing 30 tons, and of twenty wagons of 10 tons each, or a gross load of 230 tons.

From these Tables it was ascertained, that the five different descriptions of rails were on the average crushed in six years, and worn out in nine years, thus[1]—

T		Y		H		E		N	
Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.
Years.	Years.	Years.	Years.	Years.	Years.	Years.	Years.	Years.	Years.
5	7	6	7	5	7	10	13	5	8

[1] Reference may here be made to Mr. Woodhouse's Report in the Appendix (page 334), showing how the wear of these rails was tested, and how the figures giving these average results were obtained.

As the object of these experiments was chiefly to ascertain the difference between a rolled and a hammered slab, both made from inferior iron (**E** representing the former, and **H** the latter), these two kinds of rails were placed on the same line so as to compare their relative merits; and the result shows the **E** rail, with the rolled slab, to be superior at each of the eight places where the rails were tested.

The conclusion thus arrived at is, that hammering after the first welding heat, for this particular kind of iron, does not improve the enduring quality of the rails; but that rolling, which is the simplest mode of manufacture, has also the material advantage of being the best. These trials at the same time establish the fact, that it is not the wear or the diminished sectional area caused by abrasion, which produces the unsatisfactory results in the endurance of iron rails, but that it is the lamination caused by imperfect welding, and discovered by the repeated blows of the wheels in travelling at high speed. This explains the great difference sometimes exhibited in the wear of rails made in exactly the same way, but the welding in the one case being perfect, whilst in the other it has been very imperfect.

The results obtained at the Camden Town Station, however, are not applicable to the circumstances and conditions of the wear of rails under ordinary traffic; but rather to exceptional situations, where the wear is occasioned principally by the frequent use of the breaks, and by continual shunting, in a much higher degree than at any other point of the line. These results may also be attributed in part to the great weight of the locomotives, in proportion to the weight of this particular section of rail.

Rails of similar quality of iron to those marked **E**, have been tried on the Great Northern Railway, and have lasted during the passage of about sixty-five thousand trains, of a total aggregate weight of thirteen millions of tons, one-fourth part of this traffic being at a speed of about 40 English miles per hour, and the remaining three-fourths at 15 miles per hour.

These experiments on the Great Northern Railway confirm the rule laid down in Mr. R. Price Williams's Paper, "On the Maintenance of Permanent Way,"[1] viz., that the endurance of rails may be measured by the product of the speed and the passing weight. The trial-rails on the Great Northern Railway may thus be said to have borne two hundred and seventy-six millions of tons at a speed of 1 mile per hour. On the other hand, the Author's experiments at Camden Town, being made under unusual conditions of wear, do not bear out this rule; the endu-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 353.

rance of these rails being represented by only one hundred and twenty millions of tons at a speed of 1 mile per hour.

Another method of arriving at an opinion as to the endurance of these rails may be found in the renewals which have been already made on the Swedish State lines where these rails have been laid down. The present experience extends over a period of nine years on portions of the most severely-worked lines, namely, at Gottenburg and Malmö; and also during a period of six years over the whole system. The renewals on the main line have been in an increasing proportion, being in one case 30 or 40 per cent. higher than in the preceding year; and a mean calculation gives the probable result that, taking the last renewals of the rails laid down on the construction of the lines at about eighteen years from the commencement, the average life of the rails may be taken at fifteen years.

The weight which would pass over the rails during these fifteen years, judging from the reports contained in the annual accounts of the Swedish Government Railway Administration as to the traffic-returns of all the State lines during the years 1862 to 1865, may be assumed to be a yearly increase, in the gross load, of only 15 per cent. per mile, after the year 1865. The yearly increase, however, of transported goods, on the line nearest Gottenburg since 1862, has amounted to 30 per cent., and near Malmö to 18 per cent. Further, supposing the same proportion to exist between the gross and the net loads for the year 1865, it may be taken at about six millions of tons—a quantity which agrees with the results obtained on the English lines, giving for the life of the best of the three first sorts of rails, the same average life as that of the E rails. This apparently tends to confirm the correctness of the theory, that the life of rails may be measured by the product of the weight and the speed.

The rails used on the Swedish lines are mostly of the E or rolled class before mentioned. Those tried on the Great Northern Railway were also of that kind of manufacture, but of a heavier section. The speed at which the load was carried over the experimental rails on the Great Northern Railway was much higher than on the Swedish lines, being in the proportion of 20 miles on the Great Northern, to 16 miles average speed on the Swedish railways.

The conclusions which the Author has arrived at are, that no rule can be laid down for the manufacture of rails which will be applicable to every manufacturing district; but that in the case of Welsh iron, to which he has more particularly referred, it has been proved that the best method of manufacturing the rail is that now most commonly practised, viz., rolling the iron into bars, piling them, and then repeatedly rolling the pile to the finished rail, without hammering. The Author assumes that the prejudicial

result from hammering is owing to the amount of sulphur present in the Welsh iron. Where the iron contains more phosphorus, and less sulphur, as, for instance, in the Cleveland, Belgian, and French iron-districts, hammering has proved beneficial, and top slabs have been made direct from puddled balls, without the intermediate process of piling—this being, in fact, the method generally adopted in those places, and being found to answer best.

These experiments seem to indicate that two hundred and twenty millions of tons may be carried over rails, of the section and make referred to, at a speed of 1 mile per hour; so that any Railway Company, knowing the load which passes annually over their line and the speed of the trains, may, by multiplying the one into the other, and dividing two hundred and twenty millions by this product, ascertain the life of iron rails in years.

With respect to the disposal of the rails when worn out, and to the possibility of re-rolling old rails with advantage by Railway Companies located at a distance from rail-making districts, the Author thinks that for railways near the seat of rail manufacture, their best course will be to continue to dispose of the old rails to the rail mills; but for other countries, situated like Sweden, Russia, and America, it becomes important to ascertain whether it would not be more advantageous to re-roll them on the spot.

The increasing traffic, and the augmented speed of trains, together with the heavier engines now found desirable, have all a tendency to induce more severe wear, and to render necessary more frequent renewals of the rails. These renewals are executed with more and more difficulty, as the greater number of trains limits the time at disposal, whilst the stoppage of the traffic thus occasioned often results in accidents. These considerations, together with the recurring expenses of renewals, have conduced to the employment of steel, which, as a more durable material for rails, is already much used. This material has been employed either for the entire rail, or for the upper portion only, the steel top in the latter case being welded on to an iron rail.

In the case of rails with steel-tops, either the head has been entirely formed of steel, or the upper surface only has been covered with a thinner or thicker top slab, giving, say $\frac{1}{2}$ inch of thickness in the rail. The top slab has been differently applied to the rail according to the different methods used for forming the pile; so that it has either lain flat over the wearing part of the rail head, or has spanned the mass of iron with its exterior edges, thus fixing the steel without reference to the weld;—it has, in fact, been partly mechanically fastened to it. The mode of making the pile at several places where old rails have been used instead of

puddled bars, is shown in Plate 14, Figs. A, B, and C. The pile used at Dowlais for steel-headed rails made for the Swedish Government railways in September last, is shown in Fig. B; the one used at Hörde, in Germany, in Fig. A; and that employed on the London and North Western Railway, in Fig. C.

The use of steel rails has much increased in England, and many Railway Companies are introducing them as rapidly as their financial circumstances will allow.

The existence of a cheap raw material, in the shape of old rails, and the process of re-rolling them together with Bessemer steel-tops, affords an opening for carrying out the manufacture of rails profitably for Railway Companies far removed from the seat of manufacture, even when exposed to foreign competition. If such re-rolling were carried out in Sweden, instead of selling the worn-out iron rails in England, the expense of freight to and fro would be saved; and this may be reckoned at £2 per ton. The necessary cost of coal would not increase the price of rails more than about 10*s.* per ton for re-rolling rails in Sweden.

The question is thus reduced to an inquiry, whether the increased cost of manufacture due to the smallness of the quantity to be made, would amount to, or exceed, the remaining part of the difference of the freight, viz., £1. 10*s.* per ton. If so, it would then be useless to attempt the establishment of a manufacture of rails, either by private capitalists or by the Government in connection with other workshops for the repair and renewal of railway materials of different kinds, such as engines, axles, wheels, &c.

An estimate has been made, the particulars of which will be found in the Appendix (page 336), of the cost of manufacturing rails in Sweden, composed of Swedish Bessemer steel for the head, No. 2 iron for the flange, or foot, and with the remainder of the pile composed of old iron rails. The rails are of the Vignoles section, weighing 66 lbs. per yard.

From these calculations it is shown:—

1st. That according to Plan A, with the whole head of Bessemer steel, the cost per ton on an annual make of 10,000 tons is £8. 12*s.* 1*d.*; and, 2ndly, according to Plan B, with the top or wearing surface of the rail only of Bessemer steel, the cost per ton on an annual make of 6,000 tons is £8. 6*s.* 8*d.*

It therefore follows that the difference between these amounts and £10, the lowest price at which such rails can at present be imported into Sweden from England, viz., £1. 7*s.* 11*d.* by Plan A, and £1. 13*s.* 4*d.* by Plan B, respectively represents the net profit to be derived from the transfer of re-rolling operations to Sweden. In other words, providing this calculation is not too low, this represents in the first case 16 per cent., and in the second case about 20 per cent., of the whole cost of production.

In England, the London and North Western and the Great Western Railway Companies are re-rolling the worn-out rails at their own workshops, where the repairs of other railway materials are also executed, and at both these places Bessemer steel has been used for the head of the rails. The other English Railway Companies are selling their worn-out rails, as there is sufficient competition to prevent them being sold below their value.

There is only one railway company in France which has works for re-rolling the worn-out rails; and in Belgium and Prussia there are none, the rails being sold to the private rail-mills in the respective countries, and being used in connection with other iron for rail-manufacture.

In Austria, the State railways are carrying out the re-rolling of rails at their own workshops at Grätz, while the making of axles and tyres is performed at the State workshop at Neuberg.

In Russia, the rolling of the rails is executed at a workshop near St. Petersburg, altered for the purpose by a private company. The side irons and top slabs are usually of English manufacture, but sometimes the top slabs are made at home from scrap iron. English fuel is used. The Petersburg and Moscow Railway receive in exchange for their old rails three-quarters of the weight in new rails, and pay a certain sum, according to the specification, for each weight of rails received. By the other great Russian railway the old rails were at first sent to England; but for some time a private iron-work near St. Petersburg, called Ugareff, has carried on the re-rolling, on the following conditions:—The railway company finds one ton of old rails, and receives one ton of new rails, and pays £7 14s. per ton, but has then a guarantee for five years.

Having cited the case of Swedish railways, to show how far the process of re-rolling old rails may be profitably carried out, similar considerations may be applied to other railways in like circumstances, as in the British colonies and in the countries round the Mediterranean. The special conditions being different in each instance, it becomes difficult, if not impossible, to give an example that would suit every case. The principle laid down may, however, be useful as a guide as to what is to be done with the rails when worn out.

Passing to the third subject proposed for discussion in this Paper, the Author will endeavour to determine under what conditions it becomes most economical to employ either iron or steel, or a combination of these two materials, in the construction of rails.

In the following calculation it is assumed that, under a very heavy traffic, common iron rails will last five years, steel-headed rails fifteen years, and solid steel rails thirty years; that the iron rails cost £7 per ton, steel-headed rails £10 per ton, and

solid steel rails £15 per ton; and that the old steel-headed and iron rails are valued at £4 per ton, and the old solid steel at £8 per ton. With a rail section of 84 lbs. per yard, 250 tons of rails will be required for one mile of double line, and the cost of laying the rails may be estimated at £1 per ton. The following example on iron rails lasting five years, will serve to explain the way in which the subsequent Annuity Tables have been calculated:[1]—

	£.	s.	d.
250 tons, at £7 per ton	1,750	0	0
Cost of laying down	250	0	0
	£2,000	0	0

Which sum, at the end of five years, at 5 per cent., compound interest, becomes £2,552. The difference between this sum (viz., £2,552) and the value of the old rails (250 tons, at £4 per ton = £1,000) is £1,552. On referring to the Appendix (p. 337), it will be found, by the use of Table No. 2, that the annuity required to recoup this latter sum in five years is £280.

ANNUITY TABLE No. 1.

For one English mile of double line, interest being reckoned at 5 per cent., and steel-headed rails being calculated to last three times and solid steel rails six times as long as ordinary iron rails—

Where Iron Rails last	The Annuity would be for		
	Iron Rails.	Steel-headed Rails.	Solid Steel Rails.
Years.	£.	£.	£.
2	587	395	**325**
3	417	307	**271**
4	332	247	**245**
5	280	**218**	230
10	179	**163**	205
15	**134**	148	405
20	**130**	140	200

It may be objected that the prices quoted for solid steel rails in the foregoing calculations are too high. Rails of this kind have lately been sold in some districts as low as £12 per ton,[2] but for the very best quality of rails, such as those on which the experiments were made, the price was £15 per ton at the time they were manufactured. Table No. 2 has, therefore, been calculated for the different kinds and periods at the following prices, viz., iron rails

[1] It should here be remarked that the Author uses the term "annuity" to denote that amount of capital which, put out annually at compound interest at a certain rate, would in a given time accumulate to a given amount.

[2] March, 1868.

at £6, steel-headed rails at £9, and solid steel rails at £12 per ton, crediting the old iron and steel-headed rails at £3 per ton, and the solid steel rails at £5 per ton.

ANNUITY TABLE No. 2.

Where Iron Rails last	The Annuity would be for		
	Iron Rails.	Steel-headed Rails.	Solid Steel Rails.
Years.	£.	£.	£.
2	574	382	**288**
3	404	283	**233**
4	319	234	**230**
5	268	206	**174**
10	166	**149**	168
15	133	**136**	163
20	**117**	126	150

This Table shows that solid steel rails are the cheapest up to ten years' wear of iron rails; that steel-headed rails are cheapest for between ten and twenty years; and that iron rails are cheapest when they last twenty years or more.

The amount of traffic must, therefore, decide which material it is the most economical to use for the maintenance of the permanent way. For all railways where ordinary iron rails are worn out in five years, or in a shorter time, solid steel rails are the most economical, even at the price quoted in Table No. 1; but where ordinary iron rails last over ten and up to fifteen years, steel-headed rails would be the cheapest; iron rails in these cases being clearly proved to be the most expensive, although the cheapest where they last from fifteen to twenty years and upwards.

As these calculations are founded on the short experience gained up to the present time, in reference to the relative endurance of the different kinds of rails, a still longer trial is desirable.

The foregoing Tables refer to rails of the Vignoles' section. Table No. 3 has been calculated for the ordinary double-headed rail, according to the prices stated, the considerations being the same as in Table No. 2, except that the chairs have been taken into account. Allowance has been made for 140 tons of new chairs per mile, at £5 per ton, credit being given for the value of the old chairs at £2 10*s.* per ton. It may be observed that steel-headed rails are here estimated to last four times, and solid steel rails eight times, as long as ordinary iron rails, that is, making allowance for the use of both faces of each rail.

ANNUITY TABLE No. 3.

Where Iron Rails last	The Annuity would be for		
	Iron Rails.	Steel-headed rails.	Solid Steel Rails.
Years.	£.	£.	£.
2	780	379	**296**
3	551	291	**249**
4	436	244	**228**
5	366	233	**217**
10	229	**177**	199
15	183	**166**	..
20	163	**162**	..

This Table indicates that the iron rails are in no instance the cheapest; but that, on the contrary, when iron rails last only up to five years, solid steel rails have the advantage; and when the iron rails have a longer duration, then steel-headed rails are the most economical.

The experience of the durability of the steel-headed rail and of the solid steel rail may not agree with individual cases of failure, where, in consequence of defective welding, the steel head has come off, or where the solid steel rail has broken. At the same time, it must be admitted that the process of steel making, and of welding the steel slab to the rail, is, at present, in its infancy, so that great progress may yet be expected. The principle ought not to be condemned on account of individual failures.

It is to be hoped that Railway Companies having a heavy traffic will give due attention to the relative merits of the different sorts of rails, and submit them to trials on a large scale; and, on the other hand, that the steel works will strenuously endeavour to manufacture solid steel, as well as steel-headed rails, of the best kind for the purpose, so that this important question may soon be decided.

Before concluding, another subject must be taken into consideration, viz., the manner in which the safety of the permanent way constructed of the three different kinds of rail is affected by high speeds, severe climate, &c.

This subject seems of late to have engaged the attention of the railway world, and has been discussed, not only in England, but on the Continent. The Swedish Government, having undertaken the construction of railways, appointed a Committee, composed of many eminent men, to consider the subject. This Committee found it necessary to make experiments with different materials from England and Germany as well as from Sweden; and, after five years' consideration and study, the report has just been published by

Professor Styffe, the Director of the Royal Technological Institute at Stockholm.

From this report, it appears that the extensibility and tensile strength of different materials are influenced by the amount of carbon which they contain. (*Vide* Plate 14.)

The EXTENSIBILITY influenced by CARBON.

Description of Materials.	Carbon per Cent.	Extension per Cent.
Swedish Bessemer steel and Uchatius steel .	1·85 to 1·0	0·3 to 0·9
For cast steel	0·69 ,, 0·61	1·2 ,, 2·1
Bessemer steel or iron	0·42 ,, 0·33	1·9 ,, 4·0
	Spec. Grav.	
Iron from lake ores (rich in phosphorus) . .	..	0·8 ,, 3·4
Iron from Dudley (rich in slag and phosphorus)	7·5	2·5 ,, 4·2
Iron from Middlesbro' on-Tees	7·65	3·4 ,, 5·9
Puddled iron from Sweden and Low Moor .	7·77 to 7·80	6·1 ,, 9·5
Swedish iron made in the "Lancashire hearth"	7·84	7·3 ,, 7·8

The TENSILE STRENGTH influenced by CARBON.

Description of Materials.	Carbon per Cent.	Breaking Load in lbs. per Square Inch.
Swedish charcoal puddled iron . .	0·8	113,381
,, ,, ,, . .	0·7	84,265
,, Bessemer steel	0·8	90,921
,, ,, ...	0·55	86,941
,, ,, ...	0·50	71,090
,, Bessemer iron	0·20	48,102
,, puddled iron	0·70	83,441
,, ,, ...	0·70	83,716
,, ,, ...	0·6	73,492
,, ,, ...	0·6	82,344
,, ,, ...	0·5	78,432
,, ,, ...	0·7	86,049

These Tables show that the hardest material has the greatest tensile strength, but that it has the least ductility; while, on the other hand, a softer material shows a greater amount of extension.

In the diagram graphically illustrating these results (Plate 14), the percentage of carbon and of phosphorus is stated in nearly all cases. The limit for the amount of carbon seems to be for the Bessemer material 1·2 to 1·5 per cent. With a larger amount, the tensile strength, as well as the extensibility, has been found to decrease. When the amount of carbon does not exceed 0·4 per cent., and the material is not worked at too low a heat, the elongation seems to be 16 per cent., or the same as for puddled iron from the same pig iron;

and, as such Bessemer material is not only much stronger, but also more solid or homogeneous than the puddled material, it deserves a decided preference for all railway purposes. The few cases of failures of rails by breaking may be accounted for as the result of too hard a material, not perfectly manufactured, having been made at the earlier period of the introduction of the process. The experience which has now been gained should certainly prevent any recurrence of such exceptional cases.

Experiments on the tensile strength of iron and steel under the influence of extreme temperatures (as at 212 deg. and —40 deg. Fahr.), have led Mr. Styffe to the conclusion (contrary to the general belief), that the tensile strength is greater during cold than under ordinary temperatures; that is, iron or steel is stronger in winter than in summer. The reason why more breakages occur in winter than in summer is asserted to be due to the extreme cold rendering the ballast and sleepers rigid; and, therefore, elasticity given to the rolling stock, in any way, favourably affects the resistance of the rails.

If, however, the supports have the same elasticity in summer as in winter, as would be the case, for instance, with a granite rock, Mr. Styffe asserts that the same rails, either of iron or of steel, can resist a heavier blow from a falling ball at an extremely low temperature than on a hot summer's day. Although the experiments have been conducted with the utmost care and skill that science and money can afford, it seems to the Author desirable that this theory should be examined on a larger scale than Mr. Styffe has had an opportunity of doing before it can be relied upon.[1]

At a meeting of Engineers at Stockholm in March, 1867, it was decided that Bessemer steel rails, made from charcoal pig iron, might, without risk, be used 10 per cent. lighter than the English iron rails; and in Austria this decision has already been acted upon with success by the Engineer-in-Chief, Wöhler.

It must, however, be observed, that the raw material used in both cases is charcoal pig iron of a superior quality as compared with that used in England for making Bessemer rails, which may be seen from the following analyses made by two eminent chemists.

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[1] Since this Paper was read, the Author has had the opportunity of conducting some experiments on iron rails, in Sweden, by exposing them at different temperatures to the impact of a falling ball; and the results of these experiments show that, on an average, the strength of a rail in winter is not more than one-fourth of the strength exhibited by the same bar in summer. The Author has given an account of these investigations in an Appendix to the following work:—"The Elasticity, Extensibility, and Tensile Strength of Iron and Steel." By Knut Styffe, translated from the Swedish, with an original Appendix, by Christer P. Sandberg; with a Preface by John Percy, M.D., F.R.S. London, 1869.

Bessemer Swedish Pig Iron, Fagersta Works, Analysed by Kohlberg.		English Bessemer hæmatite Pig Iron, Analysed by John Percy.	
	Per Cent.		Per Cent.
Graphite	2·733	Carbon	2·993
Combined carbon	2·138	Silicon	3·080
Silicon	0·641	Manganese	0·079
Manganese	2·926	Sulphur	0·021
Sulphur	0·015	Phosphorus	0·021
Phosphorus	0·026		

These analyses show that the great difference between the two kinds of iron is the larger percentage of silicon in the English, and of manganese in the Swedish pig iron; thus explaining why the one gives a better result than the other, although worked entirely without the addition of spiegeleisen.

If there be only 0·6 per cent. of carbon in the solid steel, and 0·3 per cent. in the steel for the steel head, the safety ought to be the same for all the three kinds; and this would not influence the former calculations as to which is the best and most economical material for rails.

Having watched the development of the Bessemer process in England, as well as on the Continent, the Author believes that in that process a good and pure raw material has a greater advantage over an inferior one than in other processes; and that a superior product cannot be obtained from an inferior raw material by that method any more than by others. Indeed, a purer raw material is needed for the Bessemer process, as the phosphorus is not eliminated by that method of treatment as it is by puddling. In having mentioned Swedish material, as an example, it must not be supposed that it is wished to advocate the use of Swedish iron in this country, but simply to draw attention to the better material; as equally good charcoal iron can be supplied from Canada and India, both English colonies. It may also be remarked, that the Author's endeavour has been to arrive at the truth irrespective of prejudice, and that he has no wish to be deemed an advocate for one kind of rail more than another.

The Paper is illustrated by a series of Diagrams, from which Plates 14 and 14A have been compiled.

[APPENDIX.

APPENDIX.

Result of the Wear of the Experimental Rails at Camden Town Station, according to Mr. Woodhouse's Report.[1]

Table No. 1.

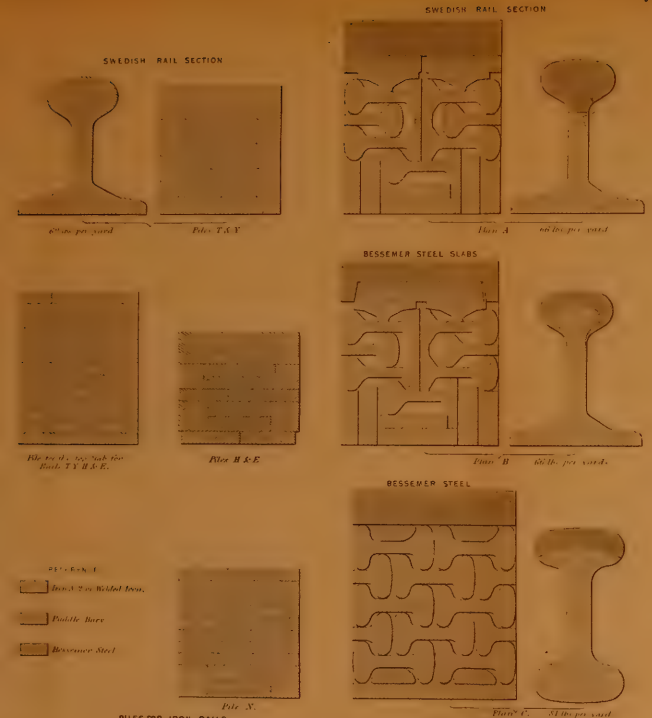
Showing the Number of Tons passed over the Experimental Rails before they were Crushed and Worn Out.

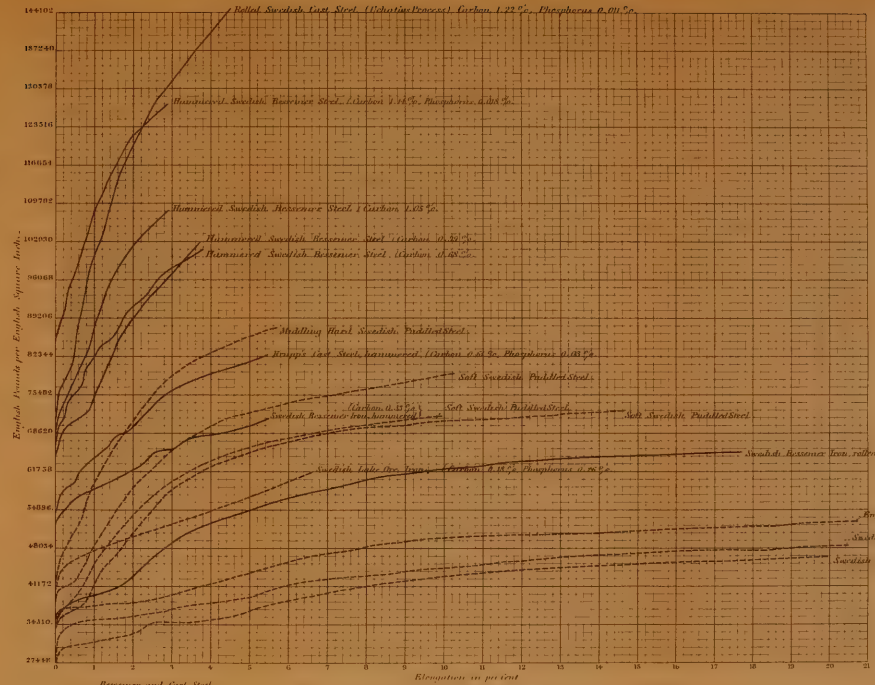
T		Y		H		E		N	
Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.
Tons	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1,380,000	1,610,000	920,000	3,450,000	920,000	1,380,000	2,300,000	3,450,000	1,610,000	2,530,000
2,070,000	2,070,000	920,000	2,300,000	1,610,000	2,300,000	4,370,000	4,370,000	2,530,000	2,760,000
230,000	2,530,000	2,070,000	2,530,000	1,840,000	2,990,000	460,000	4,370,000	2,760,000	3,220,000
2,530,000	2,530,000	1,840,000	3,680,000	1,610,000	3,220,000	2,530,000	5,750,000	2,760,000	3,680,000
460,000	3,220,000	3,910,000	4,140,000	1,840,000	4,140,000	4,830,000	6,210,000	3,450,000	4,140,000
1,610,000	3,450,000	3,680,000	4,140,000	2,760,000	4,370,000	6,210,000	7,130,000	2,070,000	4,370,000
4,370,000	5,290,000	3,450,000	4,140,000	3,450,000	4,370,000	5,290,000	7,590,000	2,300,000	4,830,000
690,000	5,750,000	2,990,000	4,370,000	3,450,000	4,600,000	8,280,000	8,510,000	3,450,000	5,290,000
4,830,000	6,440,000	3,450,000	4,600,000	3,680,000	4,830,000	6,900,000	8,740,000	4,140,000	5,290,000
6,210,000	7,130,000	3,220,000	5,750,000	3,220,000	5,060,000	7,130,000	9,430,000	6,210,000	7,360,000
6,210,000	8,510,000	4,370,000	5,980,000	3,680,000	5,290,000	8,740,000	10,580,000	5,750,000	9,820,000
11,040,000	11,960,000	7,820,000	7,820,000	4,600,000	5,520,000	7,590,000	10,580,000	4,600,000	6,210,000	6,900,000	8,970,000	3,220,000	5,520,000
..	..	5,290,000	8,280,000	1,840,000	5,750,000	11,040,000	11,960,000	2,990,000	9,430,000
..	..	7,820,000	10,120,000	3,680,000	5,750,000	14,030,000	14,950,000	8,510,000	9,960,000
..	..	11,040,000	11,960,000	4,600,000	6,210,000	14,030,000	14,950,000	..	..
..	..	..	..	2,300,000	7,820,000	14,030,000	14,950,000	..	..
..	..	..	..	7,360,000	10,580,000	..	..	..	..

Average of the Above.

Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.	Crushed.	Worn out.
3,680,000	5,060,000	4,140,000	5,290,000	3,220,000	5,060,000	6,900,000	8,970,000	3,220,000	5,520,000

[1] The figures given in this table show the number of tons that passed over the road; they must be divided by 2 to find the number of tons that passed over each rail.




Rolled Swedish Cast Steel (Uchatius Process) Carbon 1.22 % Phosphorus 0.011 %
Hammered Swedish Bessemer Steel Carbon 1.18 % Phosphorus 0.048 %
Hammered Swedish Bessemer Steel Carbon 1.15 %
Hammered Swedish Bessemer Steel Carbon 0.59 %
Hammered Swedish Bessemer Steel Carbon 0.48 %
Stubbing Hard Swedish Puddled Steel
Krupp's Cast Steel Hammered Carbon 0.85 % Phosphorus 0.035 %
Soft Swedish Puddled Steel
Swedish Bessemer Iron Hammered (Carbon 0.37 %)
Soft Swedish Puddled Steel
Soft Swedish Puddled Steel
Swedish Bessemer Iron rolled Carbon 0.38 % Phosphorus 0.072 %
Swedish Lake Ore Iron Carbon 0.18 % Phosphorus 0.06 %
Swedish Puddled Iron from Lowmoor Carbon 0.27 % Phosphorus 0.168 %
Swedish Iron refined Carbon 0.06 % Phosphorus 0.084 %
Swedish Puddled Iron
English Pounds per English Square Inch.
Elongation in per cent
Bessemer and Cast Steel
Puddled Material.

EXPERIMENTS AS TO TENSILE STRENGTH OF CAST STEEL, BESSEMER STEEL, AND PUDDLED MATERIAL, MADE BY PROFESSOR K STYFFE

PLAN OF RAIL MILL FOR REROLLING OLD RAILS WITH BESSEMER STEEL TOPS.

Railway for sending off New Rails
Grinding machine for Rails
Steam Engine
Stamping presses
Inspection
Bore &c
&c
Vice Presses
Placing for Rails to cool
Traversing platform
Steam Engine
Saw to cut off the bar ends
Rail Mill
Steam Engine
Steam Shears to cut off ends of Bars &c
Heating Furnaces
Railway for carrying rail to and across mill
Rail Shear to cut off Rails &c
Railway to carry rail to and across mill
Scale 1/48 Inch 1 Foot.

TABLE No. 2.

SHOWING the LIFE of the EXPERIMENTAL RAILS expressed in TIME.

Number of Trains consisting of an Engine of 30 tons and twenty Wagons of 10 tons each.	Life in Years at ten Trains per Day.	T		Y		H		E		N		Total Number of Rails.	
		Number of Rails.		Number of Rails.		Number of Rails.		Number of Rails.		Number of Rails.			
		Before Crushing.	Worn Out.	Before Crushing.	Worn Out.	Before Crushing.	Worn Out.	Before Crushing.	Worn Out.	Before Crushing.	Worn Out.	Before Crushing.	Worn Out.
3,000	1	3	..	..	..	..	..	1	..	1	..	5	..
6,000	2	1	..	2	1	1	1	..	..	..	..	4	2
9,000	3	2	2	2	..	5	..	..	..	2	..	11	2
12,000	4	1	2	..	2	2	1	2	..	4	2	9	7
15,000	5	..	2	4	..	3	2	..	1	2	1	9	6
18,000	6	..	..	2	4	3	1	1	..	1	2	7	7
21,000	7	2	..	1	2	2	4	1	2	1	2	7	10
24,000	8	..	1	1	..	..	3	1	..	..	2	2	6
27,000	9	2	1	..	1	..	3	1	2	2	..	5	7
30,000	10	..	1	..	1	..	..	1	..	..	..	1	2
33,000	11	..	1	..	..	1	..	2	2	..	2	3	5
36,000	12	..	..	2	2	..	1	1	..	..	..	3	3
39,000	13	..	1	..	..	..	..	1	2	1	1	2	4
42,000	14	..	..	..	..	..	..	..	1	..	2	..	3
45,000	15	..	..	..	1	..	..	..	..	..	..	..	1
48,000	16	1	..	1	..	..	1	1	1	..	..	3	2
51,000	17	..	1	..	1	..	..	..	1	..	..	..	3
54,000	18												
60,000	21	..	..	..	..	..	..	3	3	..	..	3	3
66,000													

AVERAGE LIFE IN YEARS.

T		Y		H		E		N	
Crushed.	Worn Out.	Crushed.	Worn Out.	Crushed.	Worn Out.	Crushed.	Worn Out.	Crushed.	Worn Out.
5	7	6	7	5	7	10	13	5	8

Cost of Building a Rolling Mill, for the Manufacture of 10,000 Tons of Rails per Annum.

	£.	s.	d.
Rolling Mill, train complete, with a twenty-ton fly-wheel, three boilers, pipes, shafts, cranes, &c.	2,335	0	0
Blooming-machinery, rolling-train (patent, so that no labourer is needed), rail-sawing-machine, with steam-engine, punching-machine, straightening-machines, planing-machines and lathes; all with separate steam-engines	2,240	0	0
Building of galvanized iron, according to plan (Plate 14A)	1,300	0	0
Railways and weighing-machines	640	0	0
Masonry for the boilers	810	0	0
Ditto for welding-furnaces	1,226	0	0
Foundation, culverts, &c.	380	0	0
Office buildings, warehouses, and ground	1,240	0	0
	£10,171	0	0

The cost of the machinery is less by £940 where water-power is used instead of steam-power; provided the cost of the foundations, the premises, and the channel to conduct the water, remain the same.

Estimate of the Cost of Manufacturing Rails in Sweden, rolled from worn Rails, using Swedish Bessemer Steel for the rail-head, and No. 2 iron for the foot.

(Vignoles section, 66 lbs. per yard.)

(Plan A, Plate 14.)

Rails with the whole head of Bessemer Steel.

The quantity manufactured is 33 tons per day, or 10,000 tons per year.

For the manufacture of 1 ton of Rails, there are consumed:—

			£.	s.	d.
Bessemer steel,	936 lbs.	at £10 per ton	4	3	7
Side iron and cramps,	260	„ 8 „	0	18	7
Old rails,	1,644	„ 3 „	2	4	1
	2,840 lbs.		£7	6	3

From this pile is obtained—

79 per cent. of 2,840 lbs.	= 2,240 lbs.	=	1 ton of rails.
8 „ „	= 224 „	=	2 cwt. crop ends.
13 „ „	= 376 „	=	$\frac{1}{6}$th of a ton waste.
	2,840 lbs.		

	£.	s.	d.
Coals, 16 cwt. at 13s. per ton	0	10	5
Wages	0	16	3
Cost of management and repairs of the furnaces	0	2	0
Rent of building and interest on fixed capital, £10,200, and on floating capital, £3,000, at £12 per cent. (6 per cent. for the wear of machinery and unexpected accidents)	0	3	2
	£8	18	1
Deduct value of crop ends at £3 per ton	0	6	0
Net cost per ton	£8	12	1

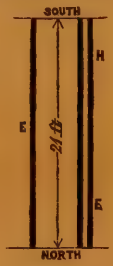
THE MANUFACTURE AND WEAR OF RAILS.

REPORT showing how the WEAR of the RAILS has been Tested, and how the Figures in the preceding Tables have been ascertained.

London and North Western Railway. Southern Division.
Engineering Department.

Statement on Mr. Sandberg's experimental Rails, laid down at Camden Yard, from November 9, 1863, to February 8, 1865.

Place No. 1.—One length of Rails under Passenger Foot Bridge. 77 Trains pass over these Rails daily.



The one side of the line.

1st Rail.

E	Laid down	9/11/63.	
	Crushed	9/9/64	5,382,000 tons.
	Taken out	21/1/65	7,590,000 ,,

The other side of the line.

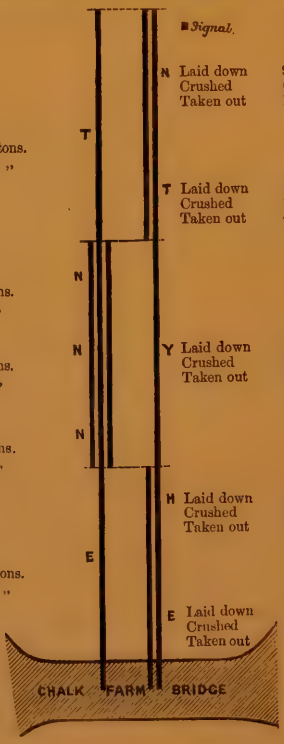
1st Rail.

H	Laid down	9/11/63.	
	Crushed	6/2/64	1,564,000 tons.
	Taken out	13/5/64	3,220,000 ,,

2nd Rail.

E	Laid down	13/5/64.	
	Crushed	31/12/64	4,094,000 tons.
	Taken out	21/1/65	4,370,000 ,,

Place No. 2.—Three lengths of Rails from signal towards Chalk Farm Bridge. 115 Trains pass over these Rails daily.



1st Rail.

T	Laid down	9/11/63.	
	Crushed	31/12/64	11,040,000 tons.
	Taken out	4/2/65	11,960,000 ,,

1st Rail.

N	Laid down	9/11/63.	
	Crushed	20/4/64	4,370,000 tons.
	Taken out	30/6/64	6,210,000 ,,

2nd Rail.

N	Laid down	30/6/64.	
	Crushed	6/10/64	2,852,000 tons.
	Taken out	2/11/64	3,220,000 ,,

3rd Rail.

N	Laid down	2/11/64.	
	Crushed	31/12/64	1,541,000 tons.
	Taken out	4/2/65	2,530,000 ,,

1st Rail.

E	Laid down	9/11/63.	
	Crushed	31/12/64	11,040,000 tons.
	Taken out	3/2/65	11,960,000 ,,

1st Rail.

T	Laid down	9/11/63.	
	Crushed	6/2/64	2,346,000 tons.
	Taken out	12/5/64	4,830,000 ,,

2nd Rail.

T	Laid down	12/5/64.	
	Crushed	31/12/64	6,141,000 tons.
	Taken out	4/2/65	7,130,000 ,,

1st Rail.

Y	Laid down	9/11/63.	
	Crushed	31/12/64	11,040,000 tons.
	Taken out	4/2/65	11,960,000 ,,

1st Rail.

H	Laid down	9/11/63.	
	Crushed	21/12/63	3,772,000 tons.
	Taken out	12/5/64	4,830,000 ,,

2nd Rail.

E	Laid down	13/5/64.	
	Crushed	31/12/64	6,141,000 tons.
	Taken out	3/2/65	7,130,000 ,,

(Signed) HENRY WOODHOUSE.

	£.	s.	d.
If the quantity manufactured does not amount to more than 6,000 tons per annum, the cost is increased by 2s. per ton. On the other hand, where water-power can be used without increasing the cost of construction of the works, and without raising the price of the raw material, the cost of manufacture is diminished by 2s. per ton, or to .	£8	10	1

The form of rail-pile (plan A) is used at Hörde Iron Works in Westphalia, for the supply of steel-headed rails to several German railways.

(Plan B,[1] Plate 14.)

Rails with Steel slab overlapping, at least half-inch thick in the head of the rail.

The quantity manufactured, 6,000 tons per year, equal to about 20 tons per day.

For the manufacture of 1 ton of Rails, weighing 66 lbs. per yard, there are required :—

				£.	s.	d.
Bessemer steel,	766 lbs.	at £10	per ton	3	9	3
Side iron for flange,	233					
Cramp-iron for flange sides,	28	" 8	"	0	18	8
Old rails,	1,813	" 3	"	2	8	4
	2,840 lbs.			£6	16	3

From this pile are obtained :—

Rails	2,240 lbs.
Waste and crop ends . . .	600
	2,840 lbs.

	£.	s.	d.
Coals, 16½ cwt. at 13s. per ton	0	10	9
Wages	0	18	4
Cost of management and repairs of the furnaces	0	2	6
Rent of building and interest on the fixed and floating capital of £12,000, at 12 per cent., of which 6 per cent. is for wear and tear .	0	4	10
	£8	12	8
Deduct for crop ends	0	6	0
Net cost per ton	£8	6	8

CALCULATION OF ANNUITIES.

For Compound Interest.

If a quantity A increases $\frac{1}{n}$ th every year for p years, it will, at the end of that time, amount to $A\left(\frac{n+1}{n}\right)p$.

Table No. 1 gives the values of $\left(\frac{n+1}{n}\right)p$ for the different values of p when $x = 20$, that is when the rate of interest is 5 per cent.

For the Annuity Tables.

If x be the quantity, which if set aside at the end of each year increases $\frac{1}{n}$ th, the annuity will at the end of p years amount to a given quantity B: then $x = (n+1)\left(\frac{n+1}{n}\right)^p - n$.

[1] This plan has been used at Dowlais for the supply of steel-headed rails for the Swedish Government Railways.

The Tables give the values of $(n+1)\left(\frac{n+1}{n}\right)^{p-1} - n$ for the different values of p when $n = 20$, that is when the rate of interest is 5 per cent.

The annexed Tables have been found by logarithms. The first shows the compound interest after a number of years, and the second the annual sum which is required to be set aside, at compound interest, to amount to a given sum at the end of a certain period.

To use No. 1, multiply the given sum by the factor in the second column opposite the number of years, and the product shows what the capital would have risen to in the time given at 5 per cent. compound interest.

To use Table No. 2, divide the given sum by the divisor in the second column, opposite the number of years, and the quotient is the annuity required to recoup the given sum after a certain period.

Table No. 1.		Table No. 2.	
Number of Years.	Capital of 1 rises by Compound Interest at 5 per cent. to	Number of Years.	At 5 per cent. Interest, the Annuity 1 will recoup a Capital of
1	1·05	1	1·000
2	1·102	2	2·05
3	1·158	3	3·152
4	1·216	4	4·310
5	1·276	5	5·526
6	1·340	6	6·802
7	1·407	7	8·142
8	1·477	8	9·549
9	1·551	9	11·025
10	1·629	10	12·77
12	1·795	12	15·917
15	2·079	15	21·779
18	2·406	18	28·132
20	2·653	20	33·0649
24	3·225	24	44·501
25	3·386	25	47·727
30	4·322	30	66·438
35	5·516	35	90·319
40	7·040	40	120·8008
45	8·985	45	159·701
50	11·47	50	209·341
60	18·68	60	353·59
70	30·43	70	588·528
80	49·56	80	971·221
90	80·73	90	1594·606
100	131·5	100	2610·04
150	1508·0	150	30139·486
200	17293·0	200	345833·2

For Example.

	£.	s.	d.
One Swedish mile of rails (single line), 700 tons at £10 per ton .	7,000	0	0
Cost of laying down	400	0	0
	£7,400	0	0

Required to find the amount which the above (£7,400) would come to after 45 years at 5 per cent. compound interest.

	£.	s.	d.
£7,400 × 8·985 = ...	66,489	0	0
Deduct for the old rails at £3 per ton	2,100	0	0
	£64,389	0	0

To find the annuity which it would be required to set aside, at 5 per cent. compound interest, to amount to £64,389 in 45 years.

£64,389 divided by 159·701 gives £403·3; and £403 6 8 is therefore the annuity required.

The annuity may also be found by dividing the present capital, minus the sale price, by the number shown in Table 2, and adding the simple interest on the capital, thus:—

$$\frac{7,400 - 2,100}{159·7} = \frac{5,300}{159·7} = 33·3;$$

add 5 per cent. on 7,400	370·
Annuity	£403·3

To find the time in which a given annuity will recoup a certain capital.

Divide the difference between the cost of new and the price of old rails by the difference between the given annuity and the simple interest on the total cost. The quotient stands in Table 2 opposite the number of years. For example:—

In how many years will the outlay for a mile of solid steel rails, on 250 tons at £15 per ton + £250 for laying them down, be recouped by an annuity of £230?

250 tons at £15 = ...	£3,750
	250
	£4,000
less the sale at £8 per ton . . .	2,000
	£2,000

Simple interest at 5 per cent. on £4,000 is £200. The divisor accordingly is 230 − 200 = 30.

$\frac{2,000}{30}$ = 66·67, nearly the number in Table 2, opposite the year 30.

Mr. Sandberg said, that when this subject was brought before the Institution two years ago by Mr. R. Price Williams, few Railway Companies had adopted steel rails; but that now nearly all lines used them to some extent. He thought conclusions had hitherto been formed without sufficient experience; but he hoped the statements of permanent-way engineers would supplement the deficiencies of his Paper. Continental railways, as yet, afforded very little experience; and it would be for England to show what had to be done in this important engineering question. On the Swedish lines steel rails were being adopted, though the traffic was comparatively light.

A simple way of ascertaining that the steel employed was sufficiently tough for rails, was to bore a hole in the bottom plate of the ingot-mould, 2 inches in diameter at the top, $1\frac{3}{4}$ inch in diameter at the bottom, and two inches deep; the piece projecting from the lower end of the ingot was broken off when cold, and having been heated to a red heat, was flattened into a cake or plate such as he then exhibited. When cold it was doubled up under a hammer, and its toughness under this treatment decided its suitability as a steel for railway purposes. Afterwards it was sent to the laboratory, and the carbon determined by the Eggertz process. The percentage of carbon and its registered No. were then marked on each piece for further reference. If under the bending-test the cake broke short, the ingot from which it was taken could be used for making springs, &c., which required harder material.

He had been furnished with some particulars respecting the use of steel rails on the London and North Western Railway, from which it appeared that steel rails were laid down at Camden Town in May, 1862, in seven different places, and one pair of rails put down in January, 1863. They were laid so as to form one side of a single line of rails, the opposite side being composed of ordinary iron rails laid down to test their comparative wearing qualities.

The effect of wear upon the ordinary iron rails was shown in the following statement drawn up by Mr. Woodhouse, the Engineer of the Permanent Way:—

"The 1st face of 5 steel rails was wearing as compared with the 2nd face of 5 iron rails.

"	4	"	"	3rd	"	4	"
"	5	"	"	4th	"	5	"
"	12	"	"	5th	"	12	"
"	6	"	"	6th	"	6	"
"	5	"	"	7th	"	5	"
"	2	"	"	8th	"	2	"
"	3	"	"	9th	"	3	"
"	5	"	"	10th	"	5	"
"	1	"	"	11th	"	1	"
"	1 (*a.*)	"	"	15th	"	in August, 1865, when the opposite steel rail was removed.	
"	1 (*b.*)	was wearing the 23rd face in March, 1867, when the opposite steel rail was accidentally broken, and was taken out.					

"(*a*.) The steel rail removed in August, 1865, was taken up to enable Mr. Bessemer to read a Paper on it at the meeting of the British Association.

"(*b*.) The steel rail removed in March, 1867, was not broken by fair wear and tear, but in consequence of some vehicles getting off the road and causing damage.

"At the time of the removal of the above-mentioned steel rails they were wearing thin, and were bruised on the outer edge. The latter of the two rails was reduced in height by about $\frac{5}{16}$ths of an inch."

All the forty-eight steel rails remaining in the road were still in good condition, and none of them had yet been turned. They were still wearing satisfactorily.

If the number of worn-out iron rails in each case cited in the previous table were summed up, it would be found to amount to a total of three hundred and fifteen, while the number of steel rails wearing on the opposite side, but in good condition, amounted to fifty. So far, therefore, as the experiments had proceeded, each steel rail was found to have worn out, on an average, six iron rails; and on these data the annuity tables had been calculated.

Mr. Edward Williams said there seemed to him some danger of false conclusions as to the cause of the superiority of rails made by the Bessemer process. These rails would wear well, not so much because they were made of steel, as that they were rolled from solid ingots.

Rails, however carefully made by the old process, being built up, were, of course, more likely to laminate than those which were made from ingots which had no layers in them. He was convinced that the question of good or bad iron rails was simply a question of welding, and that the quality of the iron was comparatively of little or no importance, except so far as one description of iron welded more easily than another, and that the kind of iron that welded most easily would make the best built-up rail, because there was the least chance of imperfect welds. A rail made from an ingot would be better than a built-up rail, but whether, price being taken into account, it might not, in many cases, be economical to use piled rails, was another question. He was inclined to think it would be so.

With regard to putting a steel top on an iron rail, it was open to the objection that steel could not, with certainty, be welded on to iron, and there would be danger of the steel head coming off under heavy work.

He thought that what were usually called the best iron rails—rails for which an extra price was paid, and which were carefully watched during their manufacture,—were really the worst rails, for the reason that the iron composing them had to be worked over and

over again, and after each working it welded with greater difficulty than before. No kind of iron welded so easily as puddled bars, and the nearer the wrought iron was to cast iron, the better rail it would make. If it were possible to make a rail direct from a puddled ball, it would probably make the best iron rail that could be produced, but, up to the present time, it had not been found possible. The system adopted in the North of England was, he believed, the best for producing really serviceable iron rails. A puddled ball, a rough, spongy sphere of about 15 inches to 18 inches in diameter, was put under a hammer and received a few blows to flatten it. Another ball was put on the top of it, and it was served in the same way; the mass was then hammered into a rectangular slab about 10 inches, or 11 inches wide, and about $2\frac{1}{2}$ inches thick. Two or three such flat slabs were then put together in a furnace, raised to a welding heat, rehammered, and rolled into the slab to form the head of the rail to be produced. This system gave just as much work as was necessary to insure soundness of the slab without overworking it. He had no doubt that this mode of working was much better than roughing down from piles composed of thin puddled bars. Indeed, long experience had proved to him that, whatever system was adopted, it depended upon the capacity of the iron for welding, and the giving it a proper heat, whether or not the rail produced would wear a long or a short time.

He thought the system of supplying exact specifications, and watching the manufacturers of rails, had not succeeded; and he would suggest one which, he believed, would produce much better rails than had been turned out lately, and at a cheaper rather than at a higher price. He would advise that Railway Companies should only apply for tenders to rail-makers of good reputation, that the onus as regarded the durability of the rails supplied should be left upon such makers, and that the Railway Companies should make no secret of the results; in fact, that there should be a periodical return of each maker's rails worn out, and the amount of work they had borne. The more public such returns were made, the better it would be for those who supplied really good rails, and the system could scarcely fail to be a better protection to Railway Companies than anything they now possessed. Of course, the prices paid for the rails should be given as well.

Sir Charles Fox thought the value of steel rails was underrated, inasmuch as it was generally considered as a question of steel *versus* iron. He did not say that the material of steel was not better for the manufacture of rails than iron, as it undoubtedly was so, but he thought that was not a fair exponent of the difference of the value of the two. An iron rail when manufactured, even in the best way, was little more than a bundle of rods; and the top slab might be compared to a piece of hoop-iron lying on the top of an anvil (the body of

the rail), when a heavy locomotive passing over it acted as a sledge hammer. If a locomotive wheel were permitted to run over a penny-piece, by its crushing weight it increased its length; but as that would not be the case with the top portion of a rail, because it was penned in lengthwise, it necessarily spread sideways, and became laminated. A steel rail was rolled from one solid ingot, not obtained in the ordinary way of casting ingots by pouring the material from the lip, but from a stopple hole at the bottom of the ladle, by which means no scum would get into the ingot, and it was consequently homogeneous and perfect. It was then rolled into a solid rail having no tendency to laminate, and that was one, and, in his opinion, the main reason why a steel rail was so much more durable than an iron one.

Having had for some years the charge of a long length of permanent way, he had carefully examined many defective rails with a magnifying glass, to ascertain the cause of their failure, and he found, in nineteen cases out of twenty, that the defects arose from lamination of the iron resulting from defective welding. It was, therefore, important to have a better, harder, and more homogeneous material for rails. But he thought that with harder rails engineers would be tempted to increase the load to be placed upon them; and that they had got into a somewhat similar dilemma to the one to which the late Mr. Robert Stephenson used to refer when he said, "It is of little use making improvements in locomotives, because the result is to induce engineers to make still steeper gradients."

Steeper gradients had, however, become a necessity; and, therefore, it was no doubt important to be able to pass heavier engines over such gradients, but in doing so care should be taken in using only such a load as would not be beyond the limit of elasticity of the material of which the rails were made; for if every time a locomotive wheel passed over a rail it sank into it to some small extent (and it undoubtedly did so), and if that sinking were not entirely recovered when the wheel passed on, he need not say the destruction of the rail would not be far distant.

Mr. T. E. Harrison, Vice-President, agreed to some extent with the remarks made by the previous speaker; and representing as he did a Railway Company in the North of England, the chief part of whose rails were purchased from the manufacturers of the district, he had minute observations taken of the wear of those rails, and he might state as the result, that on between 700 and 800 miles of permanent way of the North Eastern Railway the average duration of the last complete set of rails was found to be about fifteen years and a half; and some which were laid down in 1834 were still in use. There were rails made in Wales which had been in use in some cases more than twenty years which were

still in excellent condition. In other cases rails had to be taken up after being down only a comparatively short time. On the occasion of the examination of a number of rails taken from considerable lengths of line, which had been down for a long time, Mr. Harrison had advised that a careful analysis should be made; and it had been found that the rails which lasted the longest, contained $\frac{3}{10}$ths to $\frac{5}{10}$ths per cent. of phosphorus, and many of the rails which exhibited the least signs of wearing were such as would be generally considered bad iron. Many years ago large quantities of rails had been purchased in Wales under peculiar circumstances; they were called 'Hudson's' rails; and objections were raised against their being used, because they were manufactured under a contract, without a specification, and it must be admitted that the fracture was that of very inferior iron. They were, however, laid down on a part of the line where the traffic was very heavy; and after fifteen years' wear, many of those rails were still in good condition. This result was in accordance with the views of Mr. Williams and of Mr. Vaughan, of Middlesboro', that the specifications of Civil Engineers showed that they did not thoroughly understand the best mode of manufacturing durable rails. He accorded with that opinion; for when he compared the rails made on a more expensive specification, with a view of getting a more fibrous quality of iron, with Welsh or with North Country rails made without a specification, he found they almost invariably lasted longer than the rails made in accordance with the most elaborate specification. After consultation with two of the Directors of the North Eastern Railway, it was determined to collect samples of all those rails which had been longest down, and to place them side by side with samples of the most unsuccessful, and to have an analysis made of the whole; and then they determined to send to all the manufacturers in the locality, and to ask them to supply each a thousand tons of rails, without giving any specification. They were now in course of manufacture; and the prices at which the manufacturers had contracted to deliver them were below what they would have charged for rails made according to the specification previously used. It was intended to lay down alternate rails from each of the nine manufacturers; and they would be laid where there was the largest amount of wear. If they wore well it was assumed that the manufacturer would be prepared to supply similar rails for the future. The effect of this plan had been to put the manufacturers of the North a little upon their mettle. One sample of rails on the table had been down for twenty-four years: others had been laid in places where eighty trains a day had passed over them during fifteen years. Then there were two samples from Messrs. Bolckow and Vaughan, made without specification, which contained 0·5 per cent. of phosphorus. They were laid near the

Milford Junction, and had not been turned. Many thousands had been taken from the main line and had been laid down on some of the branches, where they would last for the next twenty years. Seeing what could be done with iron rails lasting anything like the period mentioned, the use of steel became unnecessary as a matter of economy. At the same time, on portions of the North Eastern line where there were stations and a great deal of shunting, the rails would not last more than two or three years, and in those cases steel rails had been laid down. A difficulty with regard to the iron rails arose from the test to which they should be submitted. No doubt iron which was best for wear would not stand a heavy blow, and where the rails were submitted to the test of a heavy falling weight they would be found deficient. The difficulty lay in making iron rails of sufficient hardness, and at the same time of sufficient strength for use. He could not refer to a single instance of the breaking of ordinary rails when the line was kept in good order; and the question arose, whether the test of a heavy ball should be applied; if the road was in good order he doubted whether any blow ought to come upon the rail: and even that could be met by putting in a few additional sleepers and shortening the bearings. As a question of economy, with the cost of the additional sleepers and chairs, an iron rail so treated would be cheaper than one of steel. He was an advocate for using the double-headed rail. The North Eastern system embraced a large extent of branches used for coal traffic, on which the partially worn rails were used. There were many miles of those lines on which a new rail had never been laid since the rails were first put down. These branches were maintained by rails culled from the main line, and some of them were used without being turned. Though a rail might be unfit for the main line, it would serve for a less important part of the system; and under such circumstances the double-headed rail was useful. He was not prepared to say that in all cases it was desirable to use it, because the hardest iron might be applied to one head of the rail for wear and a different quality to the bottom web; and a rail thus obtained would stand a heavy falling test; and if the rails were not going to be turned it was a matter of less importance. With regard to the use of steel, he thought if the wear he had mentioned could be got out of the iron rails it would be some time before steel would be used to a large extent; but if the size of the locomotives and the speed of the trains were further increased, steel rails might become a matter of necessity upon the main lines. The rail-makers in the North could make as good rails as they did formerly, by going back to their old mode of manufacture; and it would then be found that the ordinary rail would regain a position which, he believed, to a large extent it had for some time lost.

Mr. W. R. Innes Hopkins, being one of the Northern iron-masters referred to, did not intend to make the rails that he proposed to have tried on the North Eastern Railway according to the formula of any Engineer. He was quite certain that, as Engineers had increased their tests, they had augmented the strength of rails at the expense of their wearing power, and it was a matter of experience that a strong fibrous rail would not stand heavy traffic nearly so well as one with a hard crystalline head. In paying great attention to the wearing power of double-headed rails, they were frequently rendered brittle, and became liable to be broken, but experience showed that very far below the standard now used for testing would give a sufficiently strong double-headed rail to bear the heaviest traffic. Rails that had been laid down for many years, in the North of England, and had stood the traffic well, on being tested, were found to break at one-fourth of the weight frequently prescribed, whereas rails that had become laminated, and had quickly worn out, did not break under the operation of testing. What was technically called 'strong iron,' did not weld readily, and as the weldable property was diminished, the homogeneous character and wearing power of the rail was destroyed. On most foreign lines the Vignoles' form of rail, with a broad lower flange, had been adopted; this gave a greater opportunity for combining wearing power with strength than any double-headed section, because hard iron could be used for the head, and great strength and power of resistance to testing could be obtained in the web and the flange. He considered that the shape of many double-headed rails was far from good; they were too quickly cut in under the head; and many failures were caused by the side of the head breaking off, from not being sufficiently supported beneath. The section of the rail used by the Dutch Government showed a pear-shaped head, which he believed was as good a form as could be devised. There was some trouble at first in 'fishing' this rail, but the Dutch engineers used an arched fish, which appeared, to a great extent, to overcome the difficulty.

Mr. Fowler, Past-President, considered it rather remarkable that Mr. Harrison should have obtained better rails without a specification than when he had given specific instructions; and he could only account for it by supposing that the specification had been drawn for some other rail-making district than that in which the rails were made, for it was impossible to suppose that he would do otherwise than give such directions as would lead to the manufacture of good rails. Mr. Williams stated that the rails should be hard and crystalline, rather than fibrous. No doubt these were desirable qualities, and it was equally so that a rail should not be brittle. He could not agree in the opinion that specifications were useless, and that engineers did not know what they wanted.

On the contrary, he thought that Mr. Hopkins was mistaken, and that engineers did know what they wanted in a rail. Mr. Hopkins might suppose that, because the engineer tested against the possibility of brittleness by a falling weight, therefore he desired to have great ductility: that was a wrong conclusion; but it was important to be assured that the rail was not so hard as to be brittle; and that was the object of engineers in some of their tests. Mr. Harrison's plan of getting nine manufacturers to lay down their rails under the same circumstances would afford an excellent test, and, although without a specification, no doubt he would get good rails laid down; but then it was desirable that he should ascertain exactly the process adopted in the manufacture of those rails, and, after making careful tests, he should analyse the results, otherwise, if the manufacturers were allowed to lay down nine different kinds of rails, and no observations were taken, he would be in no better position than he was at first. In his opinion it was not desirable in the interests of railway proprietors or of the public, that engineers should abdicate their functions; but he would advise them to draw specifications, and to take pains to ascertain the process of manufacture of the iron, and to confer with the manufacturers. In former times he had got rails without a specification, paying an extra price for quality, but his expectations were not realized, and he got worse rails for a higher price.

It would be admitted that no rule could be laid down for the manufacture of rails which would be applicable to all localities. The question must be considered chiefly with regard to the mixture of iron to obtain a certain result. He believed steel would for almost all purposes eventually supersede the use of iron. But, as in the case of all new applications, caution was necessary. There could be no doubt, however, that in certain circumstances, such, for instance, as on short lines for very heavy traffic, the use of steel was most desirable. With regard to its extended use on main lines, each case must be dealt with separately, taking into account the quantity and quality of the traffic, and the varying price of the material. The price of steel rails was falling; and the difference between good iron rails and good steel rails would have a tendency to diminish. At the same time he hoped it would never so far diminish as to lead to the use of an inferior quality of steel rails. He would advise engineers to adopt the plan of having their steel rails carefully tested. The difficulties which led to the manufacture of steel that was too hard were, he believed, being gradually overcome, and existed now in a trifling degree only. The Tables that had been produced were remarkable, but he did not think that the Institution possessed at present sufficient data to induce it to regard them as satisfactory. That good steel rails would last much longer than iron rails no one could doubt; but he had no confidence

in a calculation which assumed that steel rails would last from thirty years to eighty years, though Tables, such as those exhibited by the Author, even when the life of steel rails was to some extent assumed, were no doubt useful. There were advantages in the use of steel rails which had not yet been alluded to. Taking the case of a main trunk line, such as the Great Northern, Mr. Price Williams had stated that the life of rails on that railway was eight years.[1] There was no great object in having sleepers which lasted longer than the rails, because few engineers would, on a main trunk line, put new rails on second-hand or half worn-out sleepers. But if steel rails were used lasting over a period of from sixteen years to twenty-four years, it became immediately an important object to make the durability of the sleeper as great as possible, because, in addition to the economy that would result from such an arrangement, there was a material element of convenience in not having the permanent way disturbed more frequently than was absolutely necessary. If, instead of renewing the permanent way every eight years, it became necessary to do so only every sixteen years, a great advantage would be gained. It was well known that when one-eighth of a main trunk line was always in the course of renewal, it considerably interfered with the safe working of the line. Simultaneously with the use of steel rails it would be necessary to introduce a superior quality of timber instead of what was called sleeper timber, which consisted of the tops of trees of an inferior quality. It was probable also that the form of the rail would be changed, and that, instead of the double-headed rail with fastenings composed of many parts, engineers would adopt the Vignoles form; this might be made with steel, with the bottom so wide that there would be no difficulty in having the base as large as that of the largest chairs. His own experience was in favour of a base 6½ inches in width. He considered chairs objectionable; but with a good Vignoles section of rails, a bed of great simplicity, greater strength, and more security would be obtained. That was one amongst the many advantages arising from the use of steel.

Then, again, the question of turning would no longer be considered of importance when the material lasted thirty years. He did not approve of the compound rail with a steel head and an iron bottom, as the welding was sufficiently difficult whether in iron or in steel alone, but that difficulty would be greatly increased by the attempt to make a compound rail of steel and iron. In some instances the use of such rails had been satisfactory, but in others very unsatisfactory; and he would advise Engineers to be content, either with good iron rails, or with good steel rails, and not to attempt a combination.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 353.

Mr. Isaac Lowthian Bell admitted that complete success had not hitherto attended the joint deliberations of engineers and iron-manufacturers.

Although steel in some other form than that generally used up to the present time had been alluded to, he apprehended that, as no practical plan had been hitherto devised and adopted for the manufacture of steel rails upon a large scale, it would hardly be prudent to consider any other than Bessemer steel in the present discussion. Any comparison of economy of course resolved itself into a question of cost and durability. Nothing commended itself more strongly to the mind of the manufacturer than the production of the Bessemer steel, particularly as it was occasionally practised in France, where pig-iron was run from the blast furnace into the converter, and the rail was rolled direct from the bloom, without passing under the hammer. No doubt that was a most ingenious process, and one which might be brought into universal application, but for other difficulties connected with the manufacture of Bessemer steel, which did not obtain in the manufacture of iron. In this last-named operation, the process of puddling separated in a great measure the phosphorus from the iron; whereas it was a peculiarity of the Bessemer process that the phosphorus was condensed in the steel. In selecting iron for the Bessemer process, it was important to consider the composition and the difference in the properties of the various kinds of iron to be dealt with. From his own analyses, and from the Tables of composition given in Dr. Percy's "Metallurgy," it might be assumed that in Cleveland pig-iron there was an average of about $1\frac{1}{4}$ per cent. of phosphorus; in North Staffordshire, about 1; in Derbyshire, 1; in Bowling, ·51; in South Wales, ·49; in South Staffordshire, ·41; in the Forest of Dean, ·137; in Weardale, ·10: and it was only in hæmatite iron that the phosphorus fell so low as ·047 per cent. He believed that Mr. Bessemer himself held that, by his process, he could not satisfactorily deal with iron containing above ·045 per cent. of phosphorus. The quantity of iron produced in the British Isles, fit for making Bessemer steel, was therefore extremely limited, because the total quantity of hæmatite iron was only about one-fifth of the entire yield of the kingdom. Bessemer hæmatite pig-iron, in consequence of the demand and of the limited make, was worth 80*s.* per ton, whereas Cleveland pig-iron was worth only about 42*s.* 6*d.* per ton. The important question then arose—what other supplies of iron were available for the manufacture of Bessemer steel? The total supply of pig iron in Europe was about eight and a quarter millions of tons. In France, where the manufacture of Bessemer steel was looked upon as one of great importance, there was scarcely a ton of ore fit for the manufacture of iron suitable for the process. At Lavoulte, a small district

on the banks of the river Rhone, a small portion of suitable iron ore was obtained; but by far the greater part was made from ore procured from Mokta, in Algeria, which raised the cost of the pig iron to something like £4 per ton. In Belgium, in Westphalia, and in Silesia, there did not appear to be any iron ore fit for the Bessemer converter. Norway and Sweden produced a limited quantity; but not all of that was sufficiently free from phosphorus. He had brought over from Norway a sample of ore, and he had found that the pig-iron smelted from it contained one-half per cent. of phosphorus. The Rhenish provinces raised about five hundred thousand tons of iron ore per annum pure enough for Bessemer iron. Styria and Carinthia also produced a limited supply; but he believed that a yield of two hundred and fifty thousand tons a year was all that could be depended upon from that locality. He had no knowledge of the resources of Russia; but looking at the distance of the ironworks from the shipping ports, he imagined little help could be expected from that quarter. There were no doubt other ores, as in Biscay, but so far as pig-iron was concerned, the result was that, out of the eight and a quarter millions of tons of pig-iron produced in Europe, there was only about half a million of tons suitable for making Bessemer steel.

Then the comparative cost of the manufacture of steel and of iron rails was an important question, not only as it was at present, but what it might be in the future. He thought that rails might be made from pig-iron as cheaply by the one process as by the other, so far as the mere cost of the operation for wages, fuel, and so forth was concerned, and independently of the price of the pig-iron employed. The loss, although considerable in the Bessemer process, took place at a period of the manufacture when the least amount of work had been done; and that was an advantage. He was aware that his opinion of the cost of manufacture was not admitted by the makers of the Bessemer rails. One explanation of the cost might be, that the number of rejected rails manufactured in England was far in excess of the number rejected abroad. He had been assured by a manufacturer in Styria, that he was in the habit of rolling rails for a week at a time without producing a single waste rail; but whether this proceeded from the fact that a superior kind of pig—viz., iron from pure ores, and smelted with charcoal—was used, or from greater fastidiousness on the part of the engineers in this country, he was unable to say.

He had long entertained a doubt as to the amount of confidence to be placed in some of the specifications prepared by engineers; and he still adhered to that opinion, notwithstanding the remarks that had been made. He had some time ago suggested to Mr. Harri-

son, when the Directors of the North Eastern Railway were considering the question of using a rail of steel costing as much as £12 per ton, whether some improvement might not be introduced in the manufacture of iron rails. The subject was of great importance to Railway Companies, to British iron-masters, and to the country generally, and was one which could only be properly investigated by long and patient observation of those facts which experience in the manufacture, as well as in the use of the rail, could elicit; and hence both iron makers and engineers should co-operate in any attempt to produce a good iron rail; and those who might succeed in accomplishing this would be entitled to be considered as national benefactors, by maintaining the demand for that description of metal produced in such large quantities in this country. Not long ago a rail had been taken up, which had been down for fifteen years on that portion of the North Eastern Railway on which the traffic was the largest. From previous observation, he had ventured to say that it was a bad specimen of iron, so far as purity and freedom from phosphorus was concerned. An analysis of the rail had been made with the following result:—

Silica	·08
Graphite . . .	·07
Manganese . .	·36
Sulphur . . .	·11
Phosphorus. . .	·504
Iron.	98·11
	99·234

Thus showing that it contained almost the amount of phosphorus stated by Mr. Karsten to be the extreme limit. Other rails were taken up which had been in use since 1855. The mean of two analyses of these, made by Mr. Marreco, of Newcastle, was as follows:—

	Phosphorus.	Silicon.	Carbon.	Sulphur.
One specimen contained per cent.	·513	·079	Trace.	·090
,, ,,	·307	·195	0	·109
,, ,,	·161	·168	0	Not estimated.
,, ,,	·223			

A rail just received, and apparently of serviceable quality, contained ·681 per cent. of phosphorus.

As the same kind of pig-iron might on puddling yield a product varying in quality according to the treatment it received, he had no doubt that rail-makers might produce a hard or a soft kind of iron; in proof of which he laid two samples of iron on the table, puddled from the same pig, one bright and crystalline, and the other fibrous and tough. In France this was actually done in practice, the puddler being paid different prices for the several qualities of iron. Manufacturers in England dared not

encounter the risk of making iron which, though strong enough for rails, might still not resist the severe test-blow to which Engineers subjected it; indeed when this power and species of resistance was provided for, a sufficient quantity of No. 2 bar used in the piles, and no mill cinders admitted into the blast-furnace, it seemed to him that a rail specification was considered complete.

Of such importance was the presence of phosphorus considered in France, that when it was found that railway bars were getting too fibrous, mill cinders, or ores containing phosphorus, were introduced, with the view of correcting what was regarded as a disqualification in that kind of iron; so that it might turn out eventually that this hitherto maligned substance might be considered indispensable in a good rail.

With regard to manufacturing steel by some other process, he was not without hope from what he had witnessed, and from careful study, that steel would, by the introduction of new processes, be eventually produced from iron containing phosphorus in amount far exceeding the limits laid down by Mr. Bessemer. Such a discovery, he need not say, would be a valuable acquisition to the manufacturer, to the railway engineer, and to the nation.

Mr. James Deas stated that the North British Railway Company had used solid steel rails for six years, having laid down upwards of 1,100 tons; 500 tons upon main lines, and fully 600 tons in switches and crossings. About one thousand sets of switches and crossings had been put down, and not one of them had yet worn down. Several sets of switches had been in the road for six years, while the switches of iron rails that preceded them had worn out in from six to nine months. Three years ago he had laid 250 tons of steel-headed rails, weighing 75 lbs. to the yard, in 24-feet lengths fish-jointed; they were the first rails of the kind which were made by the Dowlais Iron Company. Out of upwards of nine hundred rails, the steel had separated from the iron in only twenty-five of them, and these rails had been turned and had been left in the road with the iron heads uppermost. The steel was laid flat on the top of the rail, and not turned over the edges, as had been done in the Swedish Government rails designed by Mr. Sandberg.

He had laid down alternately, at the same time, nine solid steel rails and nine iron rails, on the outside of a 12-chain curve. The original depth of the rails was $5\frac{1}{32}$ inches. When they were examined a few days ago, the solid steel and the steel-headed rails had worn $\frac{1}{32}$ inch, whilst the iron rails had worn $\frac{5}{32}$ inch. The inside of the steel-headed rails was, however, worn much more than the inside of the solid steel rails; and this was probably accounted for by the greatest pressure of the flanges occurring at the junction of the iron and steel.

Mr. W. Menelaus said, that to make a rail of wrought iron which would endure satisfactorily, under the conditions not unusual on at least portions of most of the great lines of railway, was commercially impossible. There were inherent faults, first in the quality of the metal itself, and next in the mode of manufacture, which rendered it, in his opinion, impossible to produce a rail of wrought iron which would stand even a reasonable time under the trying conditions to which some portions of the lines must of necessity be exposed. No doubt it was possible to produce perfect homogeneity and sound welding in wrought iron, as for instance in "best-best" tyres; but this could only be done at a great cost, and, beyond all doubt, Bessemer metal could be produced cheaper than this high-class wrought iron. Even granting that wrought iron of great excellence could be produced in large quantities, which he much doubted, even the best wrought iron ever made was far inferior to Bessemer metal, at least for rails. In adopting steel for Bessemer rails there was one great security; bad steel, in the sense of impure steel, could not be made into rails. He frankly admitted that by an error of judgment, or by attempting to make the metal hard and lasting, an overdose of carbon might be given to it, and the rails would in consequence be brittle; but if this mistake were avoided, he held that bad steel could not be made into rails at all. In fact, as a matter of economy, the purer and higher the quality of the pig iron used, the cheaper must be the Bessemer steel rails produced. As far as his experience went, nothing was so bad and so wasteful as to attempt to use pig iron of low quality for making Bessemer metal: if silicon was present in excess there was a bad yield in the converter; and the presence of undue quantities of sulphur and phosphorus caused a great number of waste rails. He had found it best and cheapest to buy the highest quality of pig iron only. His experience of Bessemer metal, however, had been confined entirely to the manufacture of rails, but he had no doubt all steel makers would bear him out in these statements. He believed the only charge brought against the quality of steel rails was their brittleness, as it was called, and he supposed that rails made of Bessemer metal had broken in regular work, even when produced by manufacturers who from their long experience in the trade actually claimed pre-eminence. His opinion was that these hard rails had been made, not designedly, as a matter of economy, but simply by accident, or through an error in judgment; mistakes were less likely to happen now that considerable experience had been gained in working the metal. Excellent iron rails could be made if railway engineers would but treat ironmasters with confidence and would pay a fair price; but when a high class rail was required he was of opinion that, as far as was known at present, there was no material to be com-

pared to Bessemer metal for excellence of quality and moderate cost.

Now as to the union of the two metals in the shape of what were called steel-headed rails. Very unsatisfactory results followed the first attempts to make rails of that description; but no doubt other makers had, like himself, benefited by experience, and now a perfect junction could be insured between the iron in the body and the steel on the heads of rails. He first used plain slabs, and he had made, some years ago, by this method, a quantity of rails for the Edinburgh and Glasgow Railway. Mr. Deas reported that the rails had, so far, stood well, and he still expressed confidence in rails of this description. These rails were made with plain slabs for the tops, and the union of the two metals depended entirely on the weld. After a while he adopted a system for making steel heads, which had been long used in South Wales for iron; that was, giving a mechanical grip to the top slab in the rail-head. The slab of iron was rolled in the form of channel iron, with a rib more or less deep on each side. In the finished rail the steel was thus not only welded to the iron, but it had a good mechanical grip upon it. This plan of rolling the steel slabs in the channel form was a great improvement. All he had arrived at, however, was to get a good grip of the head: but Mr. Sandberg having the management at the Dowlais Works of the manufacture of a quantity of steel-headed rails for the Swedish Government, suggested that the horns or ribs of the channel-formed steel slabs should be deepened, so as to insure a complete envelope of steel for the head; and it was found that, in the rail rolled from the slabs designed by Mr. Sandberg, the steel actually came down into the stem of the rail, and made an excellent sound job.

It was by no means a simple matter to roll steel and iron together, as the two metals required to be worked at different temperatures; but after a little practice the men acquired sufficient skill in the management of the pile in the furnace to secure an excellent junction between the two metals, and in his opinion steel-headed rails, properly made, would be found to stand almost, if not quite, as well as rails of solid Bessemer metal, though of course they would not be reversible, having only one table of steel.

Mr. James Shaw felt from his experience at the Stockton Iron Works, that he could confirm a great deal that had been said regarding iron rails by Mr. Bell, whose remarks should be studied by all Engineers.

Many specifications had come to him from Railway Engineers; and though some of them had exhibited great practical knowledge, others had been so deficient that he had been utterly at a loss how to make the rails. Much had been said about the difference

between iron and steel, but he thought that a vast deal depended upon price, upon the judgment of Engineers, and the advice which they gave to Railway Directors. When a manufacturer quoted a price he believed that, as a rule, the lowest tender would be accepted. He knew that the Railway Company desired to get the best apparent rail at the lowest cost, and he might be disposed to believe that some of the conditions were unnecessary. The North Eastern Railway Company had taken the right course in asking a manufacturer to tender. They had said to him, "We will take you into our confidence, although our Engineers have issued excellent specifications, because you know far better how to manufacture rails than we can be expected to do." This example had been followed by a Foreign Railway Company, and the results in both cases were very satisfactory.

The question was one of great importance, inasmuch as it concerned the safety of the lives of the travelling public. He would ask whether it was creditable that there should be issued some one hundred and fifty different specifications. In France that was not the case, and even in America a uniform specification was adopted.

In regard to the manufacture of Bessemer rails a good deal appeared to have been taken upon assumption. As experience of steel rails extended back only some five or six years, it was, he submitted, somewhat rash to assume that steel rails would of necessity last sixty years or one hundred years. Steel rails had certainly the advantage of being more homogeneous, and were therefore less liable to lamination, yet hardly sufficient regard appeared to be paid to other and very important considerations relating to extra cost and the possibility of having bad steel rails as frequently as bad iron rails: he therefore could not implicitly receive the statistics which had been referred to.

Mr. Vignoles, Vice-President, thought, from the statements that had been made by the manufacturers and by all who were best acquainted with the subject, it might be concluded that if a rail from a homogeneous material could be produced the result would be better than if it were produced from a pile. Engineers knew perfectly well what they wanted, although, perhaps, not being practical manufacturers of the material, they might not be able to dictate the best way of arriving at a given result. Besides, they were controlled to a great extent in this country by Directors as regarded expense, and abroad particularly by the assumption that foreign Engineers and managers knew a great deal more than the English Engineers did. Those who had the misfortune of contending with people half informed on technical subjects, which was a dangerous thing, would know how difficult it was to satisfy the requisitions of the foreign Engineers, or of those who controlled them. Within the last few days he had received a communication from the officials

of one of the most important Governments in Europe refusing to allow an eminent manufacturer in England to replace rails made by him which had been condemned on unreasonable grounds. In order to resist serious impact, one quality of iron was required, while a different quality was called for where rails had to sustain a load, and those two perfectly dissimilar requisitions were expected to be combined in the same rail. A rail sufficiently homogeneous would combine those qualities to a certain extent. No doubt a steel rail would wear better than one of iron, and a steel-headed rail would wear better than an iron rail; but, in the latter case, the difficulty lay in combining the two. He admitted that the best iron was that which would weld the best; but it had been said that the best iron could be obtained from the puddle ball; and this had not hitherto been supposed possible. He would be willing to adopt the idea of accepting a guarantee from a manufacturer as to the quality of the metal; but he would like to know the price at which the rails were to be produced, and also the mode, and, as far as possible, the result of the wear and tear.

Mr. David Forbes observed, that in all cases homogeneous metal was to be preferred to that which was composed of more or less hard and soft particles; and therefore it became in the first place a question as to how such homogeneous metal could be obtained. Unless iron could be brought into a state of complete fusion, it would not be practicable to get a material having in all parts the same mechanical structure, or the same mechanical composition. As fused iron had not yet been found available, recourse must be had to a compound which was somewhat more fusible and easily manufactured, as, for example, cast steel, which could be produced by the Bessemer, the Siemens, or any other good process. The question became then one of price, and in that respect the Bessemer process at present had the advantage. No doubt good steel could be produced from bad materials; though in the present state of metallurgy not so as to be remunerative. It was quite possible to take the worst cast iron, and to oxidize so much of it as to leave a residue of good steel; but he considered the Bessemer rails had suffered in the estimation of Engineers from the attempts that had been made to use a material which was bad and unfitted for the purpose. He had made some experiments which had been suggested by the opinions of Mr. Siemens, that instead of using a steel rail an iron one containing phosphorus might be employed. The results showed that such a rail would be an extremely dangerous one; since, although at times very strong, such rails were liable to be very 'cold short.' It was found extremely difficult to get the phosphorus so uniformly disseminated throughout the mass as to produce in all parts the same hardness, or the same non-liability to break. The main point was to insist

upon the employment of a good raw material for the production of the Bessemer steel.

Mr. H. Conybeare was of opinion that the section of a rail materially affected its duration, and that this was especially the case as regarded the design of the head and of the upper surface or wheel-track. It was obvious that each portion of the rail had its special and definite functions and conditions to fulfil, and a careful consideration of the character of these should supply rules that would regulate with certainty the contours and the dispositions and scantling of the metal in every portion of the section, that would best conduce to the fulfilment of such conditions.

Some years ago, having occasion to design the rails for Irish and Welsh railways, he had collected, with a view to determine the best form of rail, all the sections he could obtain from the Welsh iron-works, and the London metal-brokers; and he compared and collated these with a view to ascertain the extreme range of the variations in practice, and the limits of economy and practicability in manufacture. He also calculated the strain to which each portion of the section was subjected, and considered the conditions it had to fulfil, and the extent to which these conditions were complied with in each example. Having done so, he endeavoured to establish definite rules which should fix absolutely the contour and the proportionate scantling of every portion of the rail section. These he had since carried out in practice, and the results arrived at were exhibited in the following diagrams and Tables. It would be seen that the diagrams, though also applicable either to the T rail or the double-headed rail, referred more especially to what was known as the Vignoles section. Everywhere except in England the double-headed section and the chair road had long been obsolete, and he thought it was much to be regretted that it was not so in this country. It was obviously essential to the perfection of any system of permanent way, that the jointing of the rails to each other, and the mode of attaching the rail to the sleeper, should be of such a description as to ensure absolute uniformity of gauge and of cant, and such as to admit of no jar, shake, or movement, which might loosen the fastenings, and thereby induce hammering and concussion, which must conduce to the disintegration of the bearing surface of the rail, and to the injury of the rolling stock; and judged by this canon, a Vignoles rail, directly fastened by fang-bolts into beds planed by machinery, in rectangular sleepers, was as superior to a road in which chairs intervened between the rail and the sleeper, as the best road of the latter description was to the old stone sleepered and unfished chair road. As regarded the weight of the rails, it was possible to make them too heavy; for modern rails failed not through their deficient strength as girders, but through the deficient homogeneity and hardness of texture in the

bearing surface presented to the rails, which induced the lamination and hammering out of such bearing surface under the concentrated pressure and violent impact of the wheels. It was essential that the rails should possess an amount of vertical stiffness sufficient to confine their deflection under the passing load within unobjectionable limits. But any weight or vertical stiffness in excess of what would suffice to fulfil this condition was absolutely injurious; for as a certain amount of elasticity was essential to the durability of the rails, an excess of rigidity invariably tended to destroy the rail surface, by acting as an unyielding anvil placed beneath it, between which and the hammering action of the driving-wheels the bearing surface of the rail was rapidly beaten out into laminæ, and so destroyed; and the heavier the anvil the more rapid was the process of destruction. If extra weight and speed of traffic were to be provided for, improved quality in the material was required rather than increased quantity,—a harder surface, not heavier metal.

Thus the rails most remarkable for their longevity had been also most remarkable for their abnormal weakness and deflectibility as girders; for example, a length of 25 miles or 30 miles of the original permanent way of the South Western Railway consisted of a 75 lb. rail, laid on transverse sleepers 5 feet apart from centre to centre. The strength of such a rail as a girder was therefore only equal to that of a $57\frac{1}{4}$ lb. rail laid on 3-feet bearings; and as, according to Barlow's experience, the deflection of the same rail, when supported on 5-feet bearings, was to its deflection when the supports were 3 feet apart, as 64 to 24, the flexibility of this rail was threefold that of a 75 lb. rail on 3-feet bearings. Here was, therefore, a permanent way abnormally weak and flexible, its strength being only equal to that of a $57\frac{1}{4}$ lb. rail on 3-feet bearings, and its flexibility at least four times greater than that of a 75 lb. rail on 3-feet bearings. When he last obtained particulars of this permanent way, these rails had been laid down for eighteen years, and were still in perfect order. He believed that more was lost than gained by increasing the weight of even a double-headed rail above 70 lbs. per yard, which appeared to him to be equal to the heaviest traffic; and with cross-sleepers equidistant from centre to centre, and with a section of equal weight per yard, a Vignoles road was stronger and stiffer than a chair road; for the bearing of the rail on a chair was only 3 inches, which reduced the clear bearing only from 36 inches to 33 inches, the square of which was 1,089: but the bearing of the Vignoles rail on machine-planed beds was from 9 inches to 10 inches, according to the width of the rectangular sleepers used, which reduced the clear bearing to 27 inches or 26 inches, the squares of which were respectively 729 and 676; and the strength being inversely as the square with

the sleepers 3 feet apart from centre to centre, it followed that the strength as a girder of a Vignoles rail would be to that of a double-headed rail of equal weight in a chair road, (the sleepers being the same distance apart from centre to centre,) in the ratio of 1,089 to 729, or of 1,089 to 676, or nearly as 3 to 2. He therefore considered that the weight of a Vignoles rail should never exceed 70 lbs. per yard, nor be less than 65 lbs.: the minimum would be 62 lbs., if dog-fastenings were substituted for through fang-bolt fastenings; but such a substitution was, in his opinion, much to be deprecated.

The section of a rail admitted of three primary subdivisions—the head, the vertical web, and the foot. The same division applied to the double-headed section, merely substituting a second head for the foot. Thus, the principles on which the rail-section, shown in Fig. 2, p. 363, as outlined, applied equally to the Vignoles and the double-headed sections.

The width of the head ranged in practice from $2\frac{1}{2}$ inches to $2\frac{1}{4}$ inches. The former was till lately the rule in England; but the flat-footed rails, which had almost superseded every other form of section on the Continent and in America, and which were rapidly gaining ground in England, were usually only $2\frac{1}{4}$ inches in width of head. In Mr. Brunel's latest specification for a 75 lb. double-headed rail for the Eastern Bengal Railway, the width was only 2·3 inches; on the Grand Russian Railway it was 2·3 inches; on the Cape Railway and Swedish Government lines the same; and the rail of the Kustendjie Railway, of the Royal Swedish, and many others, only 2·25 inches. He considered 2·25 inches the proper width for lines with light and medium traffic, and 2·3 inches the maximum for lines with the heaviest traffic. In fact, it could be demonstrated that nothing was gained by increasing the width above 2·3 inches. If, indeed, the wheel-treads of the rails were horizontal planes, and the peripheries of the wheels truly cylindrical, so that the contact or bearing of the wheel with and on the rail were conterminous with the width of the latter, there would be a manifest advantage in making such bearing surface as wide as possible. But in practice, the contact of the wheel and rail at any one moment was merely that of a cone laid transversely on a cylinder, and such contact, instead of extending the whole width of the rail, would, were the materials unyielding and non-elastic, be a mathematical point without length or breadth; and, after allowing for elasticity, the actual contact at any one moment had been stated by Mr. Brunel never to exceed $\frac{1}{8}$th of an inch in width. He thought this an under-estimate; but, however that might be, it was obvious that the width of actual contact at any one moment could never amount to any considerable fraction of the width of the rail, and therefore that nothing could be added to the width of

actual contact, that could in any way diminish the stress of the wheel on the wheel-tread, by increasing the width of the latter beyond the limits he had laid down. By so increasing the width of the rail-head, the overhang or false bearing of the shoulder of the rail over the vertical web that supported it was increased, and thereby, *pro tanto*, the cross strains to which the material of the rail was subjected. The contour of the wheel-tread was obviously the point of paramount importance. It was by the lamination at this surface that the rail perished. It was the weakest link in the chain, and one which, from the peculiar and exceptional conditions of the case, could not be strengthened adequately.

In ordinary cases of engineering, when a structure of given material was designed for the purpose of carrying a load, the amount of such load was first ascertained: secondly, the ultimate strength of the material; and finally, an ample margin was allowed for safety. For example, the ultimate strength of wrought iron being 25 tons per square inch, the load on a wrought-iron girder-bridge was not allowed to exceed 5 tons per square inch. But it was, unfortunately, impracticable to apply this rule to the apportioning of the bearing surface of the rails to the load on the locomotive driving-wheels. The case was a wholly exceptional one in engineering; for not even the smallest margin for safety was practicable. It was impossible to avoid loading the bearing surface to an extent much greater per square inch than the greatest that any such material would be subjected to, if it could possibly be helped; for the point of contact of the wheels with the rail, supposing the material of both to be unyielding and non-elastic, would be not a surface at all, but merely a mathematical point, and the load on the driving-wheels of a locomotive was often 11 tons, the whole of which might at any moment be thrown by a jerk on a single rail.

The only circumstance that could save the bearing surface from destruction under such an emergency was the elasticity of the wheel and the rail, which allowed the periphery of the former to flatten at its contact with the latter, and the rail surface to lap round the contact of the wheel, so as to convert what would otherwise be a bearing point into a bearing surface; and it was desirable to encourage this action as much as possible, by giving the rail as much elasticity and as flat a bearing surface as was compatible with the observance of other essential conditions.

In the case of a railway with a central guide-rail, it was obvious that the wheels of the rolling-stock should be perfectly cylindrical, and the wheel-treads of the rails horizontal planes. In such a case the pressure of the wheel-tyre would be distributed over the entire width of the rail—a condition more favourable to the durability of both tyres and rails than when the pressure on the wheels was concentrated on a scarcely appreciable fraction of the width

of the rail—as must be the case when the wheel-tread of the latter had for its contour a circular arc. It should be attempted in ordinary practice to approach these conditions as nearly as the coning of the wheels, coupled with the clearance or play of $\frac{3}{4}$ths of an inch allowed between the flanges and the inner surface of the rails, and also the allowance for the inaccuracy in the gauge and in the angle of the wheel-cant, due to imperfections in the laying and working of a chair road, would permit, by making the radius with which the profile of the wheel-tread was struck as large, and consequently the arc as nearly approximate to a plane surface, as the conditions of the case allowed.

As the wheels were coned to an inclination corresponding to the cant of the rails, such coning would perfectly accord with a flat-headed rail, provided the relative position of wheel and the rail were always kept the same by a central guide-rail; but the play allowed between the flanges and the rails, coupled with this coning to a small extent, and the inaccuracy of gauge and cant incidental to the laying of a chair road, in a far greater measure caused an appreciable amount of angular divergence between the profile of a perfectly flat wheel-tread and the rectilinear profile of the wheel-tyres. Sometimes the latter would bear on the inner edge and sometimes on the outer edge of the former. It was to obviate this that the wheel-treads had been given a rounded contour. The principle was correct; but the amount of such rounding could be demonstrated to be almost inappreciable, and was generally injuriously overdone. The proper amount of rounding to be given to the upper surface of the rail—viz., the radius with which the circular arc forming the profile of the wheel-tread should be struck—admitted of accurate determination. The angle of the arc should be twice that of the maximum angle of divergence between the profile of the cone and the wheel-tread, supposing the latter to be flat.

The amount of the portion of this angle of divergence which was due to the coning of the wheels, and the clearance or play allowed between the wheel flanges and the inner surfaces of the rails, might be thus determined. As the amount of such clearance only allowed the wheels to deviate $\frac{1}{2}$ inch on each side of their centrical position; and, as the inclination of the side of the cone of the wheel line was only $\frac{1}{20}$th, the utmost limits of such deviation could only raise one end of the axis $\frac{1}{40}$th of an inch, and depress the opposite end to the same extent; and, taking the length of the axis in round numbers as 60 inches, this would only be equivalent to an inclination of $\frac{1}{20}$th of an inch in 60 inches, *i.e.*, of 1 in 1,200, and the angle of deviation of the profile of the wheel from that of the rail head due to this cause would be, of course, the same—that was 1 in 1,200 equal to an angle of 0° 1′ 51″. To this had to be added

the angular variation in the cant and gauge of the rail due to the inaccuracies incidental to the laying and wearing of a chair road. The bed of the chair on the sleeper was 10 inches, and the bed was cut to a template; and if the limit of inaccuracy in the cutting and wearing of the bed were assumed to be about $\frac{1}{4}$th of an inch at one end or the other, this would be equivalent to a variation of $\frac{1}{40}$, or equal to an angle of 1° 51′ 1″, and this, added to the angle of variation due to the coning of the wheel and clearance, would make the total angle of divergence A B C and A′ B′ C′ on Fig. 1 equal to 1° 27′ 51″.

Fig. 1.

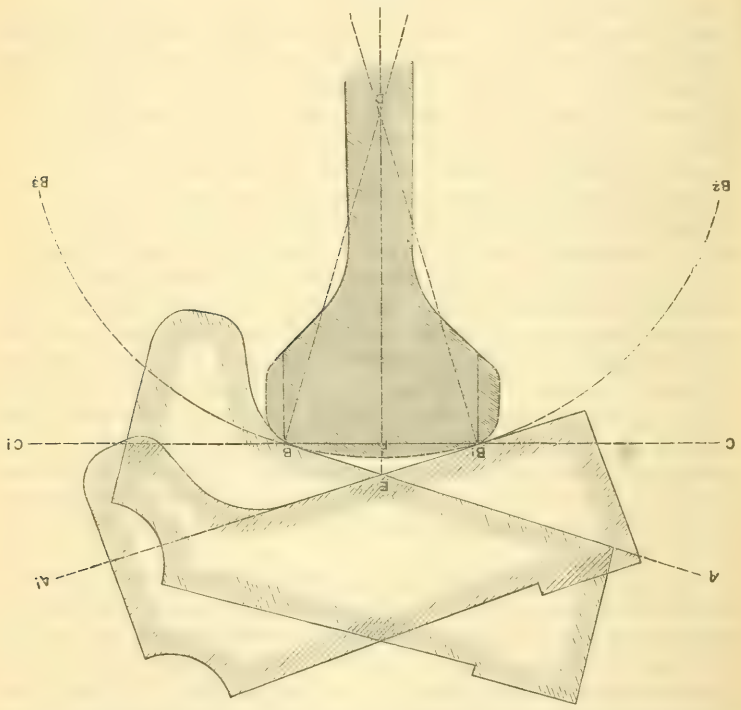


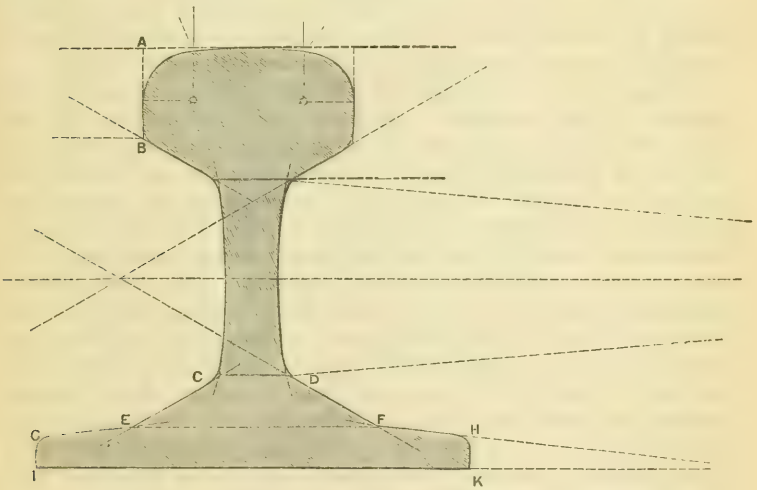
Diagram demonstrating that when B′ B = 1½ inch, and the head of the Rail is, therefore, 2½ inches wide, a radius of 40 inches will give ample curvature for the wheel-tread.
The angles D B′ B and D B B′ are each equal to 88° 32′ 9″. The angles C B A and C′ B′ A′ are thus each equal to 1° 27′ 51″, and B′ D B measures 2° 55′ 42″.

In this Figure, B′ B represented the bearing surface of a rail, say 2 inches wide, and A B and A′ B′ the extreme positions of the wheel tyre on such a rail, supposing it flat topped; these positions being inclined to the rail surface at an angle of 1° 27′ 51″. To determine the radius with which the profile of the bearing surface

of the rail must be described, so as to prevent the weight being ever thrown exclusively on either edge of the rail, and so that each portion of the surface might take its turn equally with the other in bearing the weight, draw through B and B′ the extreme points of contact of the wheels and rail surfaces, the lines B D and B′ D in a direction perpendicular to the lines A B and A′ B′, then the point of intersection of B D and B′ D would be the centre from which the circular arc forming the profile of the wheel-tread should be struck; for it was clear that the profile of the wheel contour would be tangential to this arc in every possible position of the wheels.

The angles E B′ D and E B D being obviously similar angles, therefore B′ D B was equal to twice the angle A B C, or 2° 55′ 42″, and, as the side B′ B of the triangle B′ D B was equal to 2 inches, and the opposite angle was equal to 2° 55′ 42″, the length of the sides B D and D B was 54 inches, which was, therefore, the radius with which the arc forming the profile of the wheel-tread should be struck. If B′ B was equal to only $1\frac{1}{2}$ inch, this radius would be equal to 40·75 inches. This allowed for the inaccuracy of laying and wearing incidental to a chair road, but with a Vignoles rail a much flatter one would suffice. He was, therefore, warranted in adopting 40 inches as the proper radius of the profile of the wheel-tread in all cases.

Fig. 2.



Construction of Rail Section. Half full size.
The wheel tread has a radius of 40 inches.
The vertical web is profiled with a radius of 12 inches.
The upper and lower fish planes are at an angle of 60° to each other.

The radius with which the shoulders of the wheel-tread were rounded off was at first only $\frac{1}{4}$ of an inch: this was found in-

sufficient, and the present practice ranged from a radius of ·45 inch to ·7 inch. On the Grand Russian, and in the section adopted by Mr. Samuel, the radius was only ·45 inch. In the rail chosen by Mr. Fowler for the Great Southern and Western Railway of Ireland, and also in the Royal Swedish, the radius was ·5 inch; in the Great Northern of France, ·55 inch; and in the Eastern Bengal Railway, ·6 inch.

The radius of the shoulder should not be less than ·5 inch, nor more than ·6 inch; and, in his opinion, the former dimension answered all necessary conditions, and anything more than that was injurious, as detracting from the width of the wheel-tread.

The flank of the shoulder should be vertical, as the proper function of the metal disposed in this portion of the section was literally to keep the shoulder up to the wheel, and it was obvious that the best disposition of material for this object was to carry down the flanks of the shoulder vertically till they met the upper fishing planes. This disposition of material had also the advantage of providing a better bearing for the fish-plates.

At its lower termination the vertical plane of each shoulder flank was met by the surface intended to receive the upper bearings of the fish-plate.

It was indispensable that the upper and lower bearing surfaces of the fish-plate and rail should fulfil two conditions; first, that they should be plane surfaces; and, secondly, that they should be equally inclined to the axis of the fish-bolt, which should be placed centrically between the upper and the lower bearing surfaces.

The necessity of the fulfilment of these conditions appeared to be obvious. If the surfaces were curvilinear, the principle of the wedge was excluded, and the slightest inaccuracy in the manufacture would prevent the fish from obtaining a fair and continuous bearing on the rail. It was equally obvious that the bolt which pressed these fish-plates into apposition must be centrical, otherwise the pressure upon the upper and the lower bearing surfaces would be unequal, and the fish to that extent defective. The same objection applied to inclining the upper and the lower bearing surfaces of the fish at a different angle; the pressure on the upper and the lower bearing of the fish would in that case manifestly differ in the same ratio as the sines of the angles of their upper and lower bearing surfaces, and the effect would be the same as if the angles being equal, the distance between the upper fishing-plane and the centre of the fish-bolt, and that between such centre and the lower fish-plane, differed in the same ratio.

The functions which the vertical web had to fulfil were simply to maintain the head and the foot of the rail in the same relative position with itself and each other, under any lateral or vertical strains to which they might be subjected in the working of the line. In

modern practice the centre thickness of this vertical web ranged from ·55 inch, which was little more than the minimum to which it could be rolled without unduly increasing the cost of manufacture, to ·7 inch. A favourite dimension for the centre thickness of a rib that increased in thickness towards its junctions with the head and foot of the rail was ·6 inch; but ·65 inch, or ·7 inch were common dimensions when the section of the vertical web was parallel throughout from head to foot. He had adopted in these Tables (pp. 367-8) in every case a top and bottom thickness of ·7 inch, and a thickness at the centre of ·6 inch, the profiles of the sides of the vertical web being circular, and drawn through these three points, *i. e.*, with a chord, equal to the depth of the web, and a versed sine equal to ·05 inch, *i. e.*, half the difference between the top and bottom width ·7 inch, and the centre width ·6 inch.

Horizontal lines drawn through the intersection of these arcs, with the prolongation of the fishing-planes, formed the demarcation between the head and vertical web and the vertical web and foot; therefore any one of the forty-one vertical webs in the series given in the Tables (pp. 367-8) might be joined to any of the thirty heads or to any one of the twenty-six feet, and thus about thirty-two thousand varieties of rail section might be formed from such combinations. The re-entering angle between these arcs and planes was filled in by an arc of ·3 inch radius.

The fixing of the angle, at which the fish-planes converged at 60°, was the result of a compromise. Manufacturers preferred a larger angle, so as to give the head the pear-shaped section of the Erie rail: but this increased the foot of the rail, and rendered it difficult to form a good fish, whereas with an angle of 60° as strong a fish might be formed as had ever been made. The only effect on the fish of diminishing the angle from 60° to 50° was that in the latter case an equally strong fish might be obtained with less scantling in the fish-plates and fish-bolts. But no such increase of scantlings would be necessary with the insistent fish.

The usual depth of the double-headed rail was 5 inches, but, as already shown, the strength of a Vignoles rail, laid on sleepers 3 feet apart from centre to centre, exceeded that of a double-headed rail of equal section and depth laid on sleepers the same distance apart nearly in the ratio of 3 to 2; and, therefore, to ensure the same strength and stiffness, the depth of the Vignoles rail might be, as compared with that of the double-headed rail, in the ratio of 2 to 3. In practice the depth had hitherto been in excess of this, for convenience in fishing only. The Royal Swedish rail and the Grand Russian rail had each a depth of $4\frac{5}{8}$ inches; the Morayshire, the Kustendjie, the Great Southern and Western of Ireland, and the Swedish Government rails, had each a depth of $4\frac{1}{4}$ inches, while the rails for the Cape were $4\frac{1}{2}$ inches deep, and his own

65½ lb. section, laid on the West Cork, the Cork and Kinsale, the Cork and Macroom, and the Cork and Limerick Direct Railways, had a depth of 4·3 inches, though for heavy traffic, he made the depth 4·55 inches.

He now came to the foot of the rail. The dimensions of the trapezium, C D F E, (Fig. 2, p. 363) which formed the upper portion of the foot, and the sides of which, F D and C E, constituted the lower fish planes, should be the same for all weights of rail. Its top width, C D, was ·7 inch, its bottom width 2·1 inches, and its depth ·45 inch. From C and D the profiles of the upper surface of the foot extended at an inclination downwards of 1 in 10, till they attained the full width intended to be given to the foot, and from these terminations vertical lines—G I H K—were dropped ·375 inch in depth, for the thickness of the toe, which was fixed by manufacturing considerations, and was the same in all cases, and a horizontal line drawn through I to K completed the profile of the foot.

The width of the foot should be at least sufficient to admit of through fastening, consisting of bolts passing through the sleepers, fixing into fang-nuts abutting on its lower surface. He thought the practice of nailing the rail to the sleeper by exaggerated brads, called dog-bolts, could not be too strongly deprecated. He had found a width of 4½ inches sufficient for fulfilling these conditions; and for the heaviest traffic, it appeared to him that a width of 5 inches was ample. If this width were exceeded, the difficulty of rolling, and consequently the cost of the rail, would be greatly increased.

He was aware that there were advocates for making the foot, or lower flange, very wide in proportion to the depth of the rail, in order to obtain a greater amount of lateral resistance: but regarding a problem of this sort, it might be said *solvitur ambulando*. The Vignoles section had long been in general use, both in Europe and America, and on both continents, after experience gained over a period of ten or fifteen years' working, and on a length of over 10,000 miles of railway, a width of 4 inches had been found sufficient, and was still adhered to. And if a base of 4 inches was thus sufficient with only dog-bolt fastenings, *a fortiori*, must a width of 4½ inches be ample with such superior attachment to the sleepers as was effected by through fastenings, such as fang-bolts.

He exhibited a diagram containing sections of thirty heads of rails, varying in top width from 2·25 inches to 2·5 inches, the bottom width of all being ·7 inch, and in depth of shoulder from ·9 inch to 1·0 inch, the total depth ranging from 1·34 inch to 1·521 inch, and the weight increasing from 25·76 lbs. to 32·39 lbs. per yard. On the same diagram were also shown forty-one vertical webs, varying in depth from 1·9 inch to 2·9 inches, the width at the top

and bottom being ·7 inch, and the thickness at the centre ·6 inch, the weight varying from 12·2 lbs. to 18·20 lbs. per yard. There were also shown twenty-six sections of feet, varying in depth from ·898 inch to 1·023 inch, and in width from 4 inches to 6½ inches, and in weight from 24·06 lbs. to 39·43 lbs. per yard. Every one of these heads would fit on to every one of the vertical webs,

Heads varying in Width from 2·25 inches to 2·5 inches, and in Depth from 1·340 inch to 1·521 inch, and in Weight from 25·76 lbs. to 32·39 lbs.

No.	Width in Inches.	Depth in Inches.	Depth to Bottom of Shoulder.	Weight in Lbs.
1	2·25	1·340	— ·9	25·76
2	,,	1·374	— ·925	26·32
3	,,	1·396	— ·95	26·88
4	,,	1·421	— ·975	27·44
5	,,	1·446	1·0	28·01
6	2·30	1·361	— ·9	26·55
7	,,	1·366	— ·925	27·12
8	,,	1·411	— ·95	27·70
9	,,	1·436	— ·975	28·27
10	,,	1·461	1·0	28·85
11	2·35	1·376	— ·9	27·33
12	,,	1·401	— ·925	27·92
13	,,	1·426	— ·95	28·51
14	,,	1·451	— ·975	29·10
15	,,	1·476	1·0	29·69
16	2·40	1·391	— ·9	28·40
17	,,	1·416	— ·925	29·00
18	,,	1·441	— ·95	29·60
19	,,	1·466	— ·975	30·20
20	,,	1·491	1·0	30·80
21	2·45	1·406	— ·9	29·20
22	,,	1·431	— ·925	29·81
23	,,	1·456	— ·95	30·42
24	,,	1·481	— ·975	31·03
25	,,	1·506	1·0	31·65
26	2·50	1·421	— ·9	29·89
27	,,	1·446	— ·925	30·52
28	,,	1·471	— ·95	31·14
29	,,	1·496	— ·975	31·77
30	,,	1·521	1·0	32·39

Vertical Webs, varying in Depth from 1·9 inch to 2·9 inches, and in Weight from 12·2 lbs. to 18·2 lbs.

No.	Depth in Inches.	Weight in Lbs.
1	1·9	12·2
2	1·925	12·35
3	1·95	12·5
4	1·975	12·65
5	2·0	12·8
6	2·025	12·95
7	2·05	13·1
8	2·075	13·25
9	2·1	13·4
10	2·125	13·55
11	2·15	13·7
12	2·175	13·85
13	2·2	14·0
14	2·225	14·15
15	2·25	14·3
16	2·275	14·45
17	2·3	14·6
18	2·325	14·75
19	2·35	14·9
20	2·375	15·05
21	3·4	15·20
22	2·425	15·35
23	2·45	15·5
24	2·475	15·65
25	2·5	15·8
26	2·525	15·95
27	2·55	16·1
28	2·575	16·25
29	2·6	16·4
30	2·625	16·55
31	2·65	16·7
32	2·675	16·88
33	2·7	17·0
34	2·725	17·15
35	2·75	17·3
36	2·775	17·45
37	2·8	17·6
38	2·825	17·75
39	2·85	17·9
40	2·875	18·05
41	2·9	18·20

Constants.

In all cases, the width of the top of the foot, of the bottom of the bead, and of the top and bottom of the vertical web, was ·7 inch, and the profile of the latter was struck with a radius of 12 inches. The fishing planes were inclined to the transverse axis of the rail section at an angle of 30°; the thickness of the metal at the toe of the foot was ·375 inch, from which its upper surface rose at an inclination of 1 in 10. The radius of the wheel-tread was always 40 inches, and that of the shoulder ·5 inch.

BOTTOM FLANGES or FEET, varying in Breadth from 4·0 inches to 6·5 inches, and in Depth from ·898 inch to 1·023 inch, and in Weight from 24·06 lbs. to 39·43 lbs.

No.	Breadth in Inches.	Depth in Inches.	Weight in Lbs.	No.	Breadth in Inches.	Depth in Inches.	Weight in Lbs.
1	4·0	—·898	24·06	14	5·3	—·963	31·95
2	4·1	—·803	24·64	15	5·4	—·968	32·58
3	4·2	—·908	25·22	16	5·5	—·973	33·22
4	4·3	—·913	25·81	17	5·6	—·978	33·86
5	4·4	—·918	26·40	18	5·7	—·983	34·51
6	4·5	—·923	27·00	19	5·8	—·988	35·16
7	4·6	—·928	27·60	20	5·9	—·993	35·81
8	4·7	—·933	28·21	21	6·0	—·998	36·47
9	4·8	—·938	28·82	22	6·1	1·103	37·13
10	4·9	—·943	29·44	23	6·2	1·008	37·80
11	5·0	—·948	30·06	24	6·3	1·013	38·47
12	5·1	—·953	30·69	25	6·4	1·018	39·15
13	5·2	—·958	31·32	26	6·5	1·023	39·43

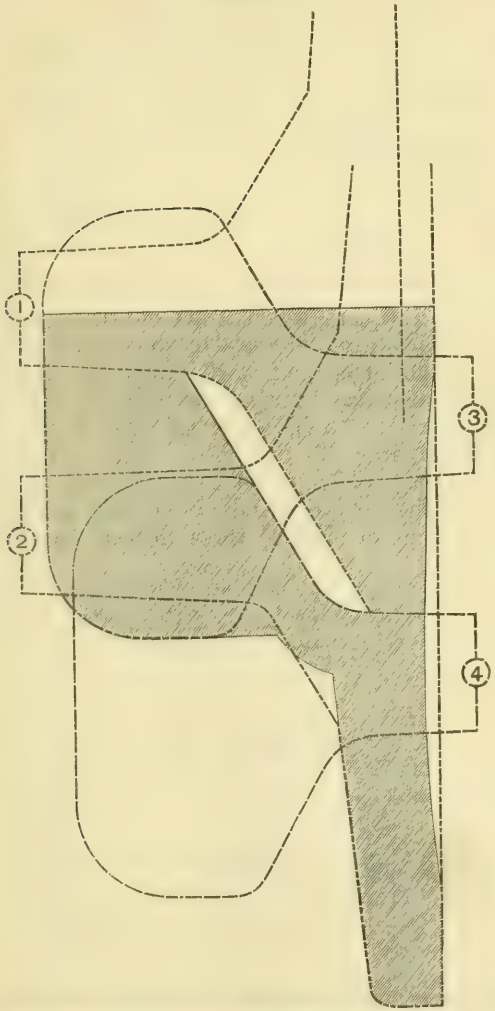
the number of combinations of the thirty heads and the forty-one vertical webs was therefore equal to 30 × 41, or 1,230 ; and every one of these 1,230 combinations of heads and vertical webs would fit on every one of the 26 sections of feet, making the total number of combinations 31,980 ; the rails so compounded varying in width of foot from 4 inches to 6½ inches ; in depth from 4·1 inches to 5·4 inches, and weighing from 62 lbs. per yard to 90 lbs. per yard. The last weight was due to the combination of the heaviest head, the highest vertical web, and the widest foot.

He did not advocate all these combinations or any extreme weight. He only mentioned the number of possible combinations to show that the Tables covered the widest conceivable range of practice. Neither did he advocate, for light or medium traffic, a greater width of head than 2¼ inches, a greater width of foot than 4½ inches, a greater depth than 4·3 inches, or a greater weight per yard than 65½ lbs. ; or for the heaviest traffic, a greater weight than 70 lbs. per yard, a greater width of head than 2·3 inches, a greater depth than 4·55 inches, or a greater width of foot than 5 inches.

With these Tables, a T square, and the little template called a "siderodograph" (Fig. 3), any one of these thirty-two thousand rail-sections might be accurately delineated in two minutes. Say an Engineer wanted a rail of the Vignoles section that would comply with the following conditions:—weight from 65 lbs. to 66 lbs. per yard ; head to have a width of 2¼ inches, and a weight of 25 or 26 lbs., foot to have the minimum width compatible with through fastenings, 4½ inches, the rest of the weight to be made up by the vertical web ; he would look in the Table and find that No. 1 head and No. 6 foot would answer these conditions, and

would weigh between them 52·76 lbs., leaving for the vertical web 12·74 lbs. if the rail were to be 65½ lbs. to the yard, and 13·24 lbs.

Fig. 3.



Siderodograph, or Iron Road Delineator. Full size.

The dotted outline No. 1, shows the application of the template to the lower fish planes, and the junction of the same with the vertical web.

" " No. 2, " " to the toe and lower flange of rail.
" " No. 3, " " to the wheel-tread shoulder and the flange of the rail head.
" " No. 4, " " to the upper fish plane, and its junction with the vertical web.

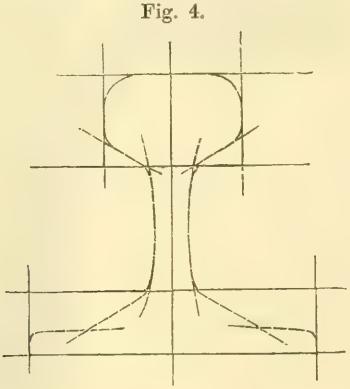
The concave circular arc at the foot of the template is the profile of the vertical web.

for a 66 lb. rail; and on looking at the Table, he would find that vertical web No. 5 would make the rail 65·56 lbs., No. 6 = 65·71 lbs., No. 7 = 65·86 lbs., and No. 8 = 66·01 lbs.: adopting the last, the weight and height would be—

——	Weight in Lbs.	Height in Inches.
Head No. 1	25·76	1·340
Vertical Web No. 8 . .	13·25	2·075
Foot No. 6	27·00	·923
Total . . .	66·01	4·338

He then with a T square would draw on the board four horizontal lines at the vertical intervals in the second column for the base of the rail, the top of the foot, the under side of the head, and the top of the same, and a vertical line for the axis of the rail; and from this axis he would prick off on each side on the two middle horizontal lines ·35 inch for the top of the foot and the bottom of the head, which would each equal ·7 inch, and other vertical lines for the vertical boundaries of head and foot. On the accompanying diagram (Fig. 4) three lines of construction were

Fig. 4.



shown as full lines, and the outline of the rail as obtained by the application of the template to such lines of construction was shown by dotted lines. The dotted lines on the full size representation of the siderodograph (Fig. 3) explained the application of the instrument to the various parts of the rail section, and it could be adjusted as desired to the lines of construction (Fig. 4) by moving

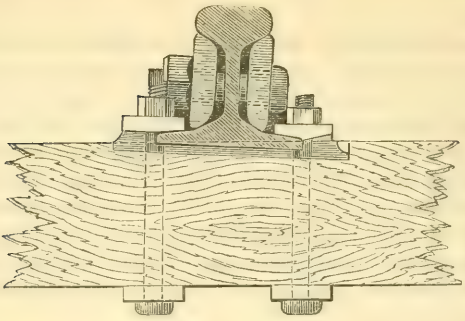
the T square up and down, and sliding the template along it like a set square.

As regarded fastenings, the only description of joint now employed was the fish-joint; and of this there were two varieties—the suspended and the insistent fish. The former had to perform two functions, the latter only one. The suspended fish had first to act as a girder, by giving vertical strength to the joint between the two rails; the fishes required, therefore, to be as long and deep as possible, to be fastened by four bolts, and to have the bearing edges as nearly horizontal as the fulfilment of other essential conditions permitted, in order to keep the ends of the two rails in accurate apposition, so that the joints might offer no obstacle to the smooth moving of the wheels.

The insistent fish was not required to add to the vertical strength of the joint, such joint being supported by the joint sleepers: the only function it had to fulfil was to maintain the extremities of the conterminous rails in accurate apposition. For this purpose a much shorter and shallower fish than would be required in suspension answered every purpose, and there might be only three bolts instead of four, as the centre bolt, acting immediately at the junction of the rails, had then a greater power of holding them in accurate apposition than it could exert in any other position. Moreover, there was no occasion to sacrifice the section of the rails to the perfection of carrying out the principle of fishing, as the angle of the bearing surface of the fish was comparatively immaterial. The suspended fish was manifestly defective as a mechanical arrangement, when compared with the supported fish, as the object to be kept in view was to approximate as closely as possible to the conditions of a bar of uniform strength. Now it was obvious that a suspended fish-joint could never offer nearly the same resistance to the load as an unjointed rail of the same bearing length; it therefore became necessary greatly to diminish the length of the bearing whenever a suspended joint occurred, and this inequality of bearing length was continued throughout the length of the rail, the bearing gradually diminishing to the joint; and as the resistance was as the square of the bearing, this inequality was manifestly incompatible with any near approximation to the conditions of a bar of uniform strength.

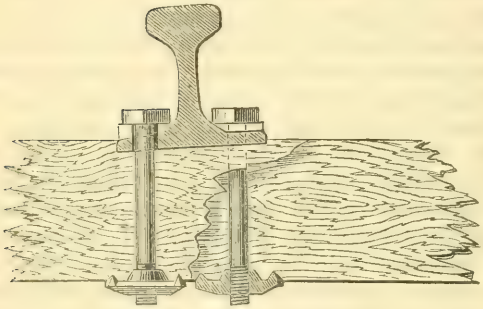
He submitted that Figs. 5, 6, and 7, showed what was the best arrangements for the fished joints and fastenings for the Vignoles rail. It would be seen that the fish was an insistent fish, and that it was a double fish, horizontal as well as vertical; for the wide horizontal under surface of the rail foot was kept in close juxtaposition with the wrought-iron bed-plate which received the ends of the rails, extending the full width of the rectangular joint-sleeper, a width of 10 inches on lines of light traffic, which, if

Fig. 5.



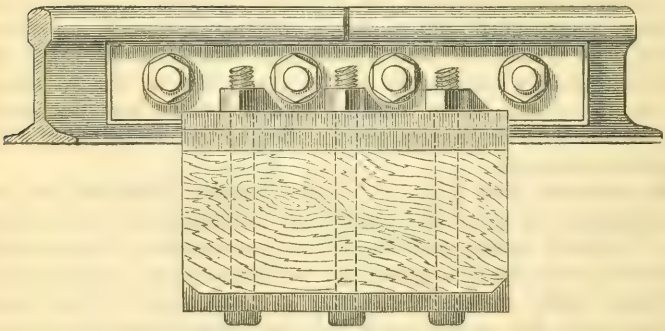
Transverse Section at Joint Sleeper.
The horizontal fish is shown unshaded.

Fig. 6.



Transverse Section at Intermediate Sleeper.

Fig. 7.



Side Elevation of Fish.
The upper horizontal fish is shown above the bed-plate.
Scale for Figs. 5, 6, and 7 :—2 inches = 1 foot.

thought desirable, might be increased to 12 inches on lines of the heaviest traffic. And the ends of these rails were fished to this bed-plate by two horizontal fish-plates with three through fastenings to each centre bolt, being placed at the most effective point, viz., the junction of the rails.

These bolts, three on each side, passed through the sleepers, and were screwed underneath it to a bar $\frac{5}{8}$ inch by $2\frac{3}{4}$ inches, acting as a common nut to the three bolts, thus making the rails practically a continuous bar of uniform resistance, and the sleeper one mass, so to speak, with the rails. Joints of this kind were quite imperceptible when running over the line, and the rails approximated far more nearly to the conditions of a continuous bar of uniform resistance than in the case of a suspended fish.

There might be an advantage in using Parsons' patent bolts for the fish and fang bolts. He had never tried them himself; but their principle was that of equalizing, by fluting the section and strength of the shank to that of the screw-tapped extremity of the bolt, so as to obtain uniform strength and elasticity; this was undoubtedly an improvement.

He always specified for fish-bolts with their inner surface concave, and the corner well preserved instead of being rounded off; by this means the bearing took its grip at the greatest possible distance from the centre of the bolt, and greater leverage was thus obtained to counteract the tendency of the nut to untwist. He had never known such nuts to work loose.

One of the greatest advantages possessed by the Vignoles road, where the rails were fixed directly to the sleepers on machine-planed beds, by means of through screw fastenings, was the absolute uniformity of gauge and cant of rails which was thereby insured, and which rendered practicable a much flatter wheel-tread, and a much narrower clearance than could be attained on a chair line; and these advantages greatly conduced to smooth running, and the preservation of rail surface and rolling stock.

The introduction of the Vignoles rail in this country had been greatly retarded by the defective manner in which it was at first, and was still sometimes laid down, viz., on half-round sleepers, and merely secured by spikes, sometimes without even a nick at the end of the rails to prevent them from travelling. No line of Vignoles rails should be passed unless the sleepers were rectangular; for the bearing of their section on the sleeper should be at least equal to that of a chair on its sleeper, and that amounted to 40 square inches. This was somewhat exceeded on a rectangular sleeper of 9 inches wide, which, with a width of 4·5 inches for the rail foot, gave a bearing of 45 inches for each point of support; but when a Vignoles rail was laid on a half-round sleeper, scarcely one-half of the requisite bearing could be obtained, and that only

on sap-wood. Another advantage of this system was that with 3-feet bearings, the clear bearing between the supports was diminished, as compared with a double-headed rail, from 33 inches to 26 inches, and the stiffness of the rail thereby increased inversely as the squares, or in the ratio of nearly 3 to 2.

He saw no reason why a steel-headed rail, of the Vignoles section, dovetailed in the manner described by Mr. Menelaus, should not last as long as one entirely of steel at double the cost.

He thought it would be admitted that puddled bars made the most enduring rails; but it was impossible to force iron of this description, with rollers such as were usually employed, into the slender toes of a wide-footed rail. He would submit that this difficulty might be overcome by employing a third roller set transversely to the other two, for rolling the under surface of the foot, an expedient very generally adopted on the Continent in rolling wrought-iron girders of similar section.

Mr. G. B. Bruce said, with regard to the specifications for rails, he was not prepared to throw the blame upon or to give the credit to Boards of Directors or foreign governments, but was rather disposed to take the responsibility upon himself in cases in which he was concerned. So far from the iron-masters having any reason to complain of the specifications of engineers, he thought that they had learnt a good deal from those specifications. The mode of manufacture which Mr. Williams had so graphically described and so strongly recommended was precisely the same which many engineers had long given in their specifications, and which the great bulk of iron-masters had been driven to adopt, by the engineers so requiring the puddle ball to be hammered in the way described. No doubt, the great secret of a good rail was that it should be homogeneous; but that was not the sole condition, otherwise it would only be necessary to fall back upon the old cast-iron rail, which was homogeneous but brittle.

He was ready to admit that in the matter of rails, as well as in many other things, tests were often carried to an injurious extent; but when judiciously applied, they were very valuable. When specifications provided that a rail should not break under a certain falling weight, and yet not bend more than a given quantity,—these conditions secured the possession of the two requisites, hardness and tenacity, so necessary for a good wearing and safe rail.

He was disposed to think that steel rails were not altogether perfect. Out of one lot of 200 tons which he had used recently, five of the rails broke, literally on being thrown out of the wagon; and in the present process of manufacture, individual steel rails were

as likely to be defective as iron rails, and could not be implicitly trusted. He had tested some flat-bottomed steel rails, punched in the lower flange, and had observed that when the holes were not near the part on which the weight of 16½ cwt. fell, the rail did not break, though the fall was 20 feet. But if the same rail was so placed that the holes were in the middle between the points of support, the rail broke at a blow with a 5-feet fall. The holes ought to be drilled and not punched in every case when dealing with steel rails.

Mr. R. P. Brereton dissented altogether from the view that good iron rails could not be made if pains were taken; or that it had become indispensable to seek for other materials, such as steel, except for special occasions. There was as yet no sufficient experience of the effect of hard steel rails upon the tyres and rolling stock—by far the most expensive part of the property belonging to Railway Companies. With regard to the deterioration in the manufacture of rails when these had to be turned out quickly and in large quantities, it was not to be expected that they should at the same time be made good. There was no desire to produce a lasting article; and when Railway Companies undertook to make their own rails, they did not make them better than the ironmasters. He had taken the pains to ascertain what had become of about 24,000 tons of rails made in Wales in 1849 for the South Wales Railway, on which there was a large mineral traffic. It was 100 miles in length and was opened in 1850. In the first nine years, out of the 24,000 tons there were only about 1,080 tons lost, or 4½ per cent. of the original quantity; and of the remainder there were at the present time 12,000 tons in use, and wearing out at the rate of about 5 per cent. per annum of the original quantity. This was principally at stations and inclines; and switches and crossings of the same iron were still in use. The life of these rails had already averaged fifteen years, and at the rate now wearing out would ultimately average seventeen. If iron-masters could make such rails years ago they could make them now; but an inducement was required which was not offered.

Mr. T. E. M. Marsh stated that the rails alluded to by Mr. Brereton were made from cold-blast iron, and a great part of it was worked into refined metal. The manufacture was well cared for. Such good rails were not now generally made. A great demand for common rails had been met by cheaper and inferior material and processes. The price had been fixed upon a sliding-scale based on the price of common bar iron, which was somewhat lower than the price of rails, the price of the latter being then about 20 per cent. or 25 per cent. higher

than that of bar iron at certain works, because it was supposed that rails were more expensive to produce. To this was added from 15*s.* to 25*s.* per ton extra. Thus, assuming bars to have been at £6 per ton, the cost of the rails would have been from £8 to £9 per ton. The rail was made from puddled bars, one of the principal advantages of that process being that the result of the yield of the puddlers might be tested every day, and at any moment. In that way a good welding quality, and a strong, solid rail, could be obtained. The rails referred to were not "cold short." Puddle balls might be badly made, and in fact frequently did inclose chilled cinder and other impurities, which would cause the iron to be crushed off the rail in large pieces.

In some districts it would probably be found better to use puddle balls direct, and not puddle bars; but the quality of the materials, processes, and appliances of the manufactures must be judged of by the engineer.

Mr. Marsh then referred to some samples of rails he had placed on the table:—

No. 1. Rail and piece of slab, made for Mr. Brunel by Messrs. Thorneycroft, in the year 1858; also small experimental lots, made in the year 1848; the top slab being formed out of a single bloom of charcoal iron. The rails were laid on the Great Western Railway, and were doing good service now, where from three hundred to four hundred engines were passing over them daily.

No. 2. Similar to No. 1, made by Mr. A. Hill. The top slab consisted of Bowling iron: used in the year 1858 and subsequently, on lines in charge of Mr. Brunel, for points and crossings, with very good results.

Nos. 3, 4, and 11. Specimens of puddled steel rail, made for railways in charge of Mr. Brunel, illustrating apparently good fracture and uncertain welds; and samples of steel tops separated by wear. These rails were generally unsatisfactory.

Nos. 5 to 9. Specimens of rails made between the years 1846 and 1850 and subsequently, for Mr. Brunel, being of the class referred to by Mr. Brereton, as having been laid on the South Wales division of the Great Western Railway, between Grange Court and Swansea, a distance of 95 miles, where they were subject to the excessively heavy wear of the inclines in the Neath and Swansea district.

The duration of the bridge rails, of which 24,000 tons were laid, was shown in the following statement:—

	Worn out.
From opening of line in 1850 to June 30, 1859 . .	1,081 tons.
„ June 1859 to July 1863 . . .	4,598 „
„ July 1863 to February 1864 . . .	763 „
„ February 1864 to July 1864 . . .	494 „
„ July 1864 to December 1864 . . .	784 „
„ December 1864 to July 1865 . . .	942 „
„ July 1865 to December 1865 . . .	820 „
„ December 1865 to July 1866 . . .	888 „
„ July 1866 to December 1866 . . .	658 „
„ December 1866 to July 1867 . . .	563 „
„ July 1867 to December 1867 . . .	557 „
	12,148 tons.

The same quality was also laid on the Great Western Railway, the Wilts and Somerset, exclusive of the Bath branch, the Berks and Hants, on part of the Oxford and Birmingham, and on heavily worked parts of the South Devon Railway, and generally, with few exceptions, on other lines forming part of the Great Western system.

The merits of the various qualities, and the best mode of obtaining good rails, were continuously and rigorously tested by Mr. Brunel, and the best results were invariably obtained from the ironmaster, who did not object to, but invited and approved rigid inspection, and desired to have the benefit of Mr. Brunel's valuable experience, and to satisfy him that all details were carried out to insure good results.

In June, 1853, Mr. Brunel addressed a letter to twelve of the principal ironmasters in these terms:—

"You are probably aware that it is a very general complaint amongst Engineers and Railway Companies that they cannot now obtain with any certainty rails of a good quality.

"There is every reason to believe that a little more care and skill in the selection of the quality of metal, at all events for a portion of the pile forming the rail, and somewhat more care bestowed in the manufacture, would secure a very superior rail to those now generally manufactured, without any very great increase of expense. I am desirous of obtaining, to lay before the Directors of the Great Western Railway Company, proposals for the manufacture and supply of about 4,000 tons of such superior quality to be used as an experiment upon a line of railway where there will be considerable traffic.

"I enclose a specification of the rail required; but I should prefer leaving the choice of means to those whose practical knowledge must be much greater than mine, and I should feel satisfied if I am assured by a respectable manufacturer that he will undertake to use his best endeavours to meet the objections raised, and to make a really good rail. I assume, although this is a time at which you are all very independent of orders, yet that you would be glad to make the attempt to regain the character which I assure you English rails are fast losing, and if you are disposed to make a trial with 1,000 or 2,000 tons, and will state the mode of manufacture you would propose, and the price, I shall feel obliged. The delivery should be immediate, or at all events early."

Extract from Specification, referred to in Mr. Brunel's letter, for Bridge Rails for Great Western Railway, June, 1853.

"One-third in quantity of the whole pile from which the rail is to be rolled is to consist of a slab of a single piece, forming the whole top of the pile, and so placed as to form the upper portion of the rail when finished. This slab shall be made of No. 2 iron, hammered, or of such other defined quality as may be mentioned in the tender and agreed upon.

"The rest of the pile shall be formed of whole lengths of bars, and no rail-ends, or awkward shaped pieces of scrap shall be used."

Mr. J. Strapp had not much experience of the relative values of steel and iron rails on the South Western Railway. Some steel rails had been laid down four years, and during that time about 10,000,000 tons had passed over them without their showing any perceptible signs of wear. At the same time iron rails had been down in the same district eight years, and probably from 19,000,000 tons to 20,000,000 tons had passed over them. He was not prepared to say that iron rails should be replaced by steel rails where they lasted so long. On the contrary, he thought that where iron rails would last over six years, steel rails, at their present price, could not be substituted with economy. He produced two specimens of rails, one of which had been down twenty-five years, on the Gosport branch, about half a mile from a station, over which not more than 4,000,000 tons had passed; the other had been down eight years in Battersea Fields, and over this 17,000,000 tons had passed; the average speed of the trains, in both cases, being about thirty miles per hour. In calculating these weights he had, of course, taken one-half the gross weight of the trains passing over the one line as that due to duty performed by one rail. Time, therefore, was not always a guide to the true worth of rails.

Mr. Peter Ashcroft produced some specimens of rails which had been used on the South Eastern Railway. Some of them had been down twenty-four years. One, an old Dover rail, put down by Sir William Cubitt, had been passed over by one hundred and five thousand trains, as nearly as could be estimated, equal to 13,000,000 tons. This was on the down line, near the Dover Station, so that every train had to pass over it. Another, of which the maker was unknown, was from the Rochester and Gravesend line, and had been down since the year 1845. It was only a 66 lb. rail, and the quality was excellent; there was a large quantity of similar rails still down on that line. Another specimen which had been down since 1865 on the Charing Cross line between Cannon Street and London Bridge, was known to have had a hundred and seventy thousand trains passed over it, amounting to 21,000,000 tons. Only one side of the rail had as yet been used

during the two years and eight months which had elapsed since it had been laid down.

He thought the South Eastern Railway Company had benefited very much by leaving, to a great extent, the specification and manufacture of the rails to the manufacturers, subject to a satisfactory guarantee.[1]

Mr. MARSH inquired whether the guarantee had worked satisfactorily. It was a question of what rails had gone back to the manufacturer.

Mr. ASHCROFT replied that one manufacturer had supplied 25,000 tons of rails, and the failures had not been more than 1 per cent. On the Charing Cross line, where the traffic was very heavy, one hundred and ninety-three trains a day passing over one line of rails, the failures were as much as 10 per cent. Care was always taken to obtain a sufficient bond of indemnity for a term of not less than seven years; and for five years on the Charing Cross line.

Mr. W. MILLS said that a large number of steel rails had been laid on the London, Chatham and Dover Railway. On a length of six miles, originally laid with iron, but which had been relaid with steel rails, he had reckoned the number of trains which passed over three different parts, and had found that in one case 8,500,000 tons had been carried, in another case 8,750,000 tons, and in a third 9,375,000 tons; the rails showed no appreciable sign of wear. Some steel rails, for stock rails for switches, had been laid down at Stewart's Lane, where formerly new iron rails were laid on an average every three-and-a-half months. Those rails had been down three years and three months, and were now in good order, and would probably last another year or more. From this latter instance it appeared, that the power of resisting wear and tear in steel rails amounted to fourteen or fifteen times that of iron rails.

Mr. JOSEPH TAYLOR thought it would be a misfortune if the impression arose that the interests of manufacturers and engineers were antagonistic. Their interests must be identical; the only

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[1] *Extract from the South Eastern Railway Company's Specification for Rails.*

"The directors will not object to receive tenders for the 10,000, 5,000, and 1,400 tons of rails respectively, manufactured according to the ironmaster's own specification, provided he can satisfy them of the sufficiency of the material to be used and the mode of manufacture, and enter into sureties for a guarantee of not less than seven years. In any case it is to be distinctly understood that this specification is intended to convey and mean, that when any of the rails are once laid down and being run over, any perceptible lamination, crushing, splitting, or breaking taking place within the period of the seven years (not being fair wear and tear), such rail or rails shall be subject to a total rejection without being turned over, and must be cast aside and replaced by other sound rails at the contractor's cost. Those rails laid down at stations and within the distance signals are excluded from the obligations of this clause, except they are found unsoundly manufactured."

difference being that the engineer wanted the best rail for the least money, and the manufacturer wished to make the best rail he could, and to get the best price for it.

There was room for wider difference of opinion, as to the best means of obtaining the best rails, and the question seemed to be narrowed into that of specifications or no specifications. He was not prepared to say that engineers ought to throw away specifications altogether, and put themselves entirely into the hands of the ironmaster; but it was possible that specifications had been pushed too far. He believed they were framed, in the first place, from the best possible information to be obtained; but he thought engineers shut themselves out from improvement and discovery in the trade, when they adhered for some years to the same specification. There had been some inconsistency in the way manufacturers had been compelled to work. It was only reasonable that, if a manufacturer was required to make a rail to produce certain results, he should be at liberty to make it according to the best of his judgment. Specifications had apparently been directed too much to the production of a high quality of bar-iron, to the neglect of the wearing quality of the metal. The heavy falling test, and the heavy suspending test, tended to produce bar-iron of high quality, but that iron was deficient in hardness and wearing quality. A little hardness might be admitted into the manufacture of rails with great advantage; and yet the rails should be sufficiently tough to resist any impact in the course of the ordinary traffic. Considering the comparative scarcity of steel-producing ore and the high price of steel rails, he thought that, for some time at least, the bulk of the supply of rails must be from iron; and so long as a thoroughly good iron rail could be made for from £6. 10s. to £7. per ton, to last fourteen or sixteen years, of which there was no doubt, he did not consider that the days of the ironmaster were numbered.

Mr. W. Adams stated that, in the month of October, 1862, 20 tons of Bessemer steel rails were laid down on the North London Railway, over which two hundred and fifty-four thousand two hundred and fifty trains, estimated to weigh 38,137,500 tons, had passed. He had lately measured them and found that they had worn down about $\frac{3}{16}$ths of an inch. He thought that each head might wear down about $\frac{1}{4}$th of an inch, and this gave the means of estimating the durability of the rails. Between thirteen thousand and fourteen thousand rails had since been laid, and he was informed that there had not been a single failure in one of them. Some crossings leading into Dalston Junction had been laid between three years and four years, and the rails were still in good working order.

Mr. Zerah Colburn had received a letter from the general

manager of the Erie Railroad, enclosing a report to the Chairman of the line, in which he stated that during the month of January upwards of one thousand rails had been broken on that line, and also that he believed the month of February would show a still worse result. Another correspondent had informed Mr. Colburn that within his knowledge, on the Hudson River Railroad, a double line, 144 miles in length, in one day, one hundred and thirteen rails had been found broken, during what was called a 'cold snap.' He had received a letter from a friend in Eastern Canada, three or four weeks ago, where possibly the temperature was lower than on the lines mentioned, and the mercury at the time the letter was written was 41° Fahrenheit below zero. At Toronto there had been unusual cold, and the mercury had ranged from 13° to 17° below zero. He had no reason to doubt the statements as to the breakages of the rails.

Rails in the United States were usually of the Vignoles section, and weighed 64 lbs. to 74 lbs. to the yard. The Manager of the Erie Railroad had asked his directors to authorise him to complete the renewals for this year, to the extent of 25,000 tons, in steel, and not one steel rail had broken, although their weight was only 56 lbs. to the yard, and some steel rails had been down for the last five years. He might add that the Hudson River Railroad was then being entirely relaid with steel rails.

Mr. W. Bragge said, in reference to Mr. Colburn's statement as to the serious disaster on the Erie Railway, for such he called the great destruction of rails, the engineer had stated that the month of February would show a greater destruction of iron rails; but he went on to state that the only portion of the line on which trains could run with safety and speed was that portion laid with steel rails, and that no fault could be found with the 10 miles of track laid with the Bessemer steel rails; of these only one had broken during the winter, and no lamination and very little wear was perceptible. It should be borne in mind by those who were using steel rails, that iron rail-makers had the experience of thirty years or forty years: whereas steel rail-makers had been really at work only since the end of the year 1861. Upon him first devolved the duty of offering steel rails for sale; at that time the steel rail was looked upon with doubt and distrust, and only by offering rails to make into points and crossings, on trial, to be paid for when they had earned their value, was it possible to sell them in England. He claimed for the makers of steel rails, that they had availed themselves of every branch of scientific knowledge which could be brought to bear upon their work; and he contended that the progress of seven years had not been unsatisfactory.

Mr. R. Price Williams observed that on the North London and the London, Chatham, and Dover Railways the life of iron as compared

with steel rails was certainly of the briefest, while on the other hand the iron rails on the South Eastern Railway appeared to have shown an amount of endurance almost as remarkable as the highly phosphorized iron rails on the North Eastern Railway.

The consideration of the use of steel instead of iron rails was, after all, an engineering and economical question, which a more extended experience of the superior endurance of steel could alone determine. As far, however, as he could gather, there could be no question as to the preference of steel rails on main lines exposed to heavy traffic and high speeds, where the maximum life of iron rails did not exceed eight years.

The accuracy of the data on which the calculations of the Author's table were based had been called in question; but he had carefully gone through them with Mr. Sandberg, and had found them perfectly reliable. Objection had also been made to the extended period taken for the life of steel rails; he apprehended that the Author had only assumed such as affording the only available means of comparison with iron rails of a proportionably long life, such as might be anticipated where they were exposed to the small wearing action of light traffic. He thought, however, that twenty years' life for steel rails was quite sufficient for all purposes of comparison, as it was evident that where iron rails had a life of even fourteen years, it was cheaper, at the present prices of steel rails, to use that material.

He was unable to comprehend why Mr. Bell, at the outset of his interesting account of the iron rail manufacture in the Cleveland district, should lay so much stress upon the superior advantages afforded by the process of puddling, in getting rid of the phosphorus, when it appeared from his subsequent remarks that the presence of this substance in certain proportions was essential to the production of a sound and durable iron rail. That an excess of phosphorus did conduce to the hardness of iron rails there could be no question; but he thought most engineers who had experience of cold short iron would confirm the opinion, that such additional hardness was obtained at the greatly increased risk of sudden and perhaps disastrous breakage of iron rails.

He was disposed to think that the efforts alluded to, as being made to produce sound iron rails out of highly phosphorized Cleveland iron, would prove unsuccessful; if, however, any practicable means could be devised for getting rid of the phosphorus, and of producing good steel out of Cleveland iron, the discoverer would undoubtedly confer a great benefit, not only upon that district but upon the country generally.

He had prepared a tabular statement with the view of showing, that when compared with the present and future advantages to be derived from the substitution of steel for iron rails, the difference in first cost was not of the importance that might at first be imagined.

TABULAR STATEMENT, showing how an ANNUITY of 10*s.* 5⅛*d.* per Ton will Recoup the difference between STEEL and IRON RAILS (£6. 10*s.* per ton) in a period of 20 Years.

DR.	Cash advanced at 5 per cent. Interest, £6. 10*s.*		Annuity, £0·5215795.	CR.
	Principal Recouped.	Interest.		
	£.	£.		£.
To 1 Year's Instalment	0·1963130	0·3252665	To 1 Year's Annuity	0·5215795
2 „ „	·2064010	·3151785	2 „ „	·5215795
3 „ „	·2167295	·3048500	3 „ „	·5215795
4 „ „	·2275585	·2940210	4 „ „	·5215795
5 „ „	·2389400	·2826395	5 „ „	·5215795
6 „ „	·2508870	·2706925	6 „ „	·5215795
7 „ „	·2634255	·2581540	7 „ „	·5215795
8 „ „	·2766010	·2449785	8 „ „	·5215795
9 „ „	·2904330	·2311465	9 „ „	·5215795
10 „ „	·3049540	·2166255	10 „ „	·5215795
11 „ „	·3202030	·2013765	11 „ „	·5215795
12 „ „	·3362125	·1853670	12 „ „	·5215795
13 „ „	·3530280	·1685515	13 „ „	·5215795
14 „ „	·3706755	·1509040	14 „ „	·5215795
15 „ „	·3892135	·1323660	15 „ „	·5215795
16 „ „	·4086745	·1129050	16 „ „	·5215795
17 „ „	·4291040	·0924755	17 „ „	·5215795
18 „ „	·4505605	·0710190	18 „ „	·5215795
19 „ „	·4730830	·0484965	19 „ „	·5215795
20 „ „	·4967430	·0248365	20 „ „	·5215795
	6·4997400	3·9318500		£10·4315900
Principal . .	£6·4997400		As per Contra.	
Interest . .	3·9318500			
	10·4315900			

Annuity required for 1 mile single line, £62. 11*s.* 9*d.*
(Iron rails and steel rails, 75 lbs. per yard.)

It would be seen that by dealing with the difference in cost between iron and steel (£6. 10*s.* per ton), as a deferred annuity, the small annual payment of 10*s.* per ton, during a period of twenty years, would recoup the principal with interest at 5 per cent. during that period. He might mention that on the main line of the Great Northern, where the average life of an iron rail was only eight years, the cost of renewals of the rails alone amounted on an average to £1 per ton per annum. It was evident, therefore, that under such circumstances the adoption of this principle of deferred annuities would ensure a saving of at least 50 per cent.

Mr. Bidder, Past-President, had never in the course of his practice pretended to dictate to the manufacturers how iron should be treated; but he had always endeavoured to obtain the best quality. Engineers were often overruled by their masters, the Directors; and there was apparently only one species of test they were capable of appreciating, and that was the lowest price. Whether as regarded locomotives, or steam-boats, or the manufacture of rails, he should consider it simple affectation to assume that he, as an Engineer, had such a knowledge of details that he could dictate the mode in which they should be constructed or produced. He knew one instance of the position he desired to lay down, where in the case of some steam-ships, the result was that when a sum of about £120,000 had been spent in six steamers, five had never been used at all; and the only one that was used did not make a single voyage without loss. As regarded iron rails, every manufacturer, urged by his own particular interest, directed his attention to the mode of manufacture most suitable to his own locality and the material he had to deal with. Now wherever Mr. Bidder was permitted to have his way, he specified what he wanted, the test, the power of the metal, and its other qualities; and then he said to the manufacturer that was what he required, and those were the tests which he should apply; and he then advised the acceptance of the tender after judging of the character of the men who tendered. He necessarily inferred that they were men satisfied with their own mode of manufacture, and that he might rely upon them to make the iron in the way they stated. By that means he had a much better surety than if he had tried to force upon them a mode of manufacture to which they had not been accustomed.

With regard to rails, all views as to the peculiar class of metal suitable for rails had been, from the first initiation of railways, subject to violent anomalies. He remembered a time when everybody assumed that only cast iron was fitted for rails, when all at once it turned out that wrought-iron rails were much more durable. It must be borne in mind that, on a railway, no rail could be broken by pressure. Take a bearing 3 feet long, and an engine 30 tons in weight, rolling over it at a speed of 40 miles an

hour. It was well known that in 3 feet a rail would bend more than $\frac{1}{4}$ of an inch before it would break; but if there were no rail at all, at 40 miles an hour the wheel of an engine would not deflect the $\frac{1}{8}$th of an inch from gravity; therefore, if a rail deflected more than $\frac{1}{8}$th of an inch, no further pressure from the engine could occur. But what had to be dealt with in rails was impact and rubbing; the latter being the most serious question. He did not know how a test for the grinding of a locomotive wheel could be applied, unless by means of a huge grindstone; and that would not give the exact effect.

Mr. Bessemer had been a great benefactor to railways and metallurgy in general: he had given an impulse, the effect of which could hardly at present be foreseen; but he believed the result would be to produce eventually a cheap and good rail. He did not care so much about its tensile powers, but rather its capacity to sustain the grinding impact of a locomotive engine, running at the rate of 40 to 50 miles an hour.

At the present day the popular cry was to close the capital account of companies. But if it were proved beyond doubt that a rail which cost £14 per ton was the one to be adopted in lieu of the present rail at £7 per ton, who was to provide the extra £6 or £7 per ton? On railways which were not in a condition to pay any dividend at all, if the capital account were closed, and rails were introduced which would eventually produce great economy, he was afraid the result would be equivalent to confiscation; for suppose some 10,000 tons of rails, at an extra cost of £70,000, were laid down, and this sum were to be taken out of the preference dividends, that would prevent their receiving any dividend for the time being; and that he would call confiscation.

Mr. T. A. Rochussen stated that the Author of the Paper had mentioned the mode of welding first brought into operation at Hörde, in Prussia. The Plan C (Plate 14) was first adopted in the year 1851, when the coal and mineral traffic had increased to such an extent, that the ordinary iron rail did not suffice to resist the increased weight. The puddling of fine-grained iron led to the puddling of steel, which not only was applied to rails, but it gradually became a staple manufacture of the country. About two years previously he had produced two rails manufactured according to that process; and only two or three days ago he had an opportunity of inspecting some of the same rails at Oberhausen, where they had borne a traffic of 42,000,000 tons. The rails weighed 56 lbs. to the yard, yet only one side was worn; the other was untouched, and these rails would probably not be turned for another six months. That welding process had been carried on now for more than seventeen years, and was still largely in operation; compound rails were used to a greater extent than both solid steel rails and

solid iron rails together. The difficulty of welding was greater with Bessemer steel than with puddled steel; and it had been found necessary to increase the weight of steel in the slab, so as to throw the weld into the web, as represented by Plan A (Plate 14). This process was only applied to the Vignoles section of rail; since there would be no saving in having the reversible opposite head in steel, leaving simply the small piece of iron between. It was very difficult to get the iron web from the steel head in the old rails.

He thought that the fracture of American rails, which had been mentioned, was due in a great measure to their unfavourable section, which was too shallow.

The Hörde works, in Prussia, had gone further than introducing the weld of steel and iron. They had for a number of years made different systems of iron angle-bars, with steel heads suspended between them. One system, which he exhibited, had been used for some time on the Brunswick Railway, and was a most advantageous mode of supporting a limited amount of steel by a larger web of iron.

Mr. Benjamin Baker observed that, in testing an iron rail against one of steel, of lighter section, but of equal stiffness, care should be taken that they were representative rails of equal average quality; so that a hard steel rail might not be tested against a soft iron one. He thought engineers had ample data to enable them to predict what the durability of such rails would be. The maximum stress on the rails could readily be ascertained, since it would be equal and opposite to that on the springs of the engine, the varying deflections and corresponding pressures of which might be noted in the ordinary working of the engine, at different rates of speed, over various portions of the line; the stress being known, the strain and deflection might be accurately computed. The comparative stiffness of similar sections of steel and iron rails was known to average as 4 to 3, and the strength as 5 to 3. It followed from this that the stiffness of Mr. Fowler's 84-lbs. section, if rolled in iron, would be equalled by a steel rail of similar but reduced section, weighing 72½ lbs.; and the strength would be equalled by a 69-lbs. steel rail.

With the section of rail adopted by Mr. Fowler, at 5 feet bearings, the solid rails bore a deflection on an average of 10½ inches; those with drilled holes, only 2½ inches; while those with punched holes snapped with less than ⅜ths of an inch deflection. Those rails were manufactured by the Dowlais Company from tough steel, of exceptionally uniform quality, the tensile strength varying very little in any experiment from 35 tons per square inch; and the breaking weight applied at the centre of the 5-feet bearings averaged 29 tons for the solid rails, 19¾ tons for the drilled rails, and only 13½ tons for the punched rails. To break those rails in a testing

machine, at the rate of sixty per minute, would require 52 effective horse-power for the solid rails, and less than one horse for the punched ones; and the knocking about which the respective rails would sustain, without injury in ordinary working, would be nearly proportional to those amounts. The ultimate deflection of the punched rails was identical with that of cast-iron rails of similar section; hence, in one sense of the word, they were equally brittle. A curious fact, bearing upon the position of holes in the flanges of rails, was worth noting. In the rails above mentioned, the two holes at each sleeper were placed 4 inches apart, measured on the centre line of the rail, and on alternate sides of the web, so that the loss of section was that due to one hole only. Now theoretical considerations indicated that the resistance of the rail would be increased by making another hole opposite the existing one, notwithstanding the double loss of section. It seemed rather an odd way of strengthening a rail, to punch a hole $1\frac{1}{8}$ inch diameter through its weakest part: but after making every correction, theory indicated a gain of 10 per cent., and this result was corroborated by direct experiment. It was found upon trial that, whilst with one punched hole the rails broke under $13\frac{1}{2}$ tons' pressure, with two holes, placed opposite each other, of similar size, they sustained $14\frac{1}{2}$ tons.

Captain H. W. Tyler had been accustomed for many years past to hear constant complaints against the manufacture of rails. It had been said that the manufacturers had lost the art of making rails—that the introduction of the hot-blast had enabled them to work up inferior ores—that it was impossible to obtain either good material or good workmanship—and that, in fine, good durable rails, such as were formerly supplied, were not to be got at any price. It was also said that rails were wearing out in this country in six months, in situations where they formerly lasted for years; and that those sent out of this country for foreign consumption were worse than those manufactured for home consumption. He had quite recently read a letter, from the other side of the Atlantic, from a gentleman of great experience, who did not believe that English manufacturers could now make durable rails, and who thought that there was no remedy but the employment of steel. Last summer he saw steel rails being laid down on lines in the United States, which cost, including transport and a very heavy duty, about £25 per ton. Only a few weeks ago, he had inquired into an accident in the Penge tunnel of the London, Chatham, and Dover Railway, which was occasioned by the failure of a rail, certainly very badly made, the top of which had fallen away in six pieces, and he saw many near it failing in a similar manner. During a recent inspection of the Grand Trunk Railway of Canada, he found that rails laid down within the last few years had been

failing to an extraordinary extent, and that portions of the line relaid with new rails were obliged to be again renewed in from three to five years, while the older rails were still necessarily kept in the track.

Now he had been carefully considering this question, both in England and in America; and particularly with reference to Canada—where, in consequence of the severity of the climate, rails of good quality were still more required than in England. The road was there in a perfectly rigid condition, for, say five months in the year, and the thermometer sometimes −40°, with the frost penetrating 5 feet into the ground. But under those circumstances the durability of the rails was very various; some of them lasting six times as long as others, under the same description of traffic. He found this was not a question of price; for strangely enough the cheaper rails had lasted longer than those for which a higher price had been paid, in some cases at the suggestion of manufacturers, to ensure greater durability. The failures appeared to be irrespective of the specification, and of tests applied. The principal defect was undoubtedly imperfect welding; and those rails which had worn best were generally those which showed on their fractured sections coarse crystals, and what would be called inferior quality. He did not believe that all the defects of manufacture which had been witnessed or experienced were due to faulty specifications. In truth, the engineers had generally consulted the manufacturers in drawing up those specifications. The difficulty had been to obtain durable rails under any specification. And when the number of specifications was complained of, for he had heard a manufacturer saying the other day that he possessed copies of two hundred and fifty different specifications, it must be remembered that a different specification was necessary in the case of each manufacturer, and of each section of rail, and was allowable in the case of each engineer.

In regard to tests, he believed that harm had been done by requiring manufacturers to make rails subject to the test of too heavy a falling weight. He had heard rails spoken of as being extra good because they would stand 17 cwt. falling 25 feet. Such rails were no doubt defective in other essential qualities.

In answering the question how to get a durable rail, it must be first determined what was required in a rail. A rail had often enough been compared to a continuous girder: but it was much more; for while it was required, like a girder, to resist compression principally in its upper, and tension chiefly in its lower chord, it was further required while deflecting very slightly, to wear gradually away under traffic on its upper flange, and to resist such wear and tear to the utmost. He by no means agreed in comparing the action of the wheel and the rail to a hammer and anvil,

because when the rolling weights inflicted a blow, they did so with the intervention of springs. When the rails were shallow, or wanting in depth, the blows became more serious, and failures by crushing at the ends, even when the joints were fished, were more apt to occur; but when the section was deep, and deflection was immaterial, the fish was more perfect, and a rolling, crushing action was the principal effect to be encountered.

In regard to the best form of rail, whatever the reason might be, it was certain that the double-headed section of rail was mostly adopted in England: while on the continent of Europe and America, such a section was only exceptionally seen. There were two principal reasons for the adoption of the double-headed section: rails of that section had a broader base by means of chairs, and they might be turned so as to wear out four instead of two edges. But, on the other hand, there were strong reasons against their adoption. They were raised higher over the sleepers, having the chairs below them: an amount of metal was put into the chairs which might with greater advantage be put into the rails: they could not, as a matter of manufacture, be made equally durable and serviceable in both heads: and when turned, they were more or less defective, and unserviceable.

With the Vignoles rail, on the other hand, the engineer and the manufacturer might combine to make a hard durable head without fear of a rail that would break in the track, because they could at the same time use fibrous material in the lower flange: and with this section all risk of loose keys was avoided, and there was also the advantage of fewer parts.

It was a prevalent idea that the Vignoles rail was not a good form of rail for traffic at high speed, but he could not, himself, see the objection. He believed, on the contrary, that when deep in section, with a good broad base, and laid on square cross-sleepers at a proper distance apart, it formed the safest permanent way that could be constructed for any speed.

In regard to quality, that to some extent depended upon the form. As he had already said, a harder and more brittle head could be used with the Vignoles than with the double-headed section. Any rail, whatever might be the quality which would not crush from bad welding, would last for a considerable time. He had an aversion to steel-topped rails, knowing that the steel and the iron welded at different heats, and believing that under the most careful system of manufacture, a large proportion of steel-topped rails must, sooner or later, fail from the separation of the steel from the iron. He had seen numerous cases, in different situations, where the steel had come off bodily, and he conceived that even the steel tops, which were originally well united, must be liable, in consequence of being rolled out under the traffic,

sooner or later, to separate. He therefore thought that the statement in the Table was deceptive. The general question of the relative advantages of steel, as compared with iron, granting that the manufacturers would still make good iron, was simply one of price. Every one must admit the advantage of a homogeneous rail, the structure of which rendered lamination impossible; but it was not every Railway Company that could afford to pay a high price for steel rails for other than exceptional parts of their line.

He believed that, while guarantees were good in their way, and particularly in England, when rails could easily be returned to the makers, there was one method which would be better in the end than specifications or tests, and that was the unreserved publication of the results. If all engineers would combine to collect and record the price, the wear and tear, and the durability of each sample of rails from the various makers, and to publish their records annually with the reports of the companies, the manufacturers would be subjected to a wholesome competition with each other, which could not but be attended with the best effects.

Mr. J. A. Longridge said that the first malleable iron rails were made by his father at the Bedlington Iron Works. There was a strong contest in those days as to the comparative merits of malleable-iron rails and cast-iron rails; and the principal objection against the malleable-iron rails was that they laminated and exfoliated. Engineers were then in favour of cast-iron rails in preference to wrought-iron, and among them was George Stephenson. The first wrought-iron rails were laid on a private railway for conveying coals to the Bedlington Iron Works; and to George Stephenson's credit it must be said, that when he saw that although they did bend they recovered their form again, he at once recommended their adoption, instead of cast-iron rails, although he had a pecuniary interest in the latter. The manufacturers could still make as good, or better malleable-iron rails than were produced at that time, or when the London and Birmingham Railway was in course of construction; and if the manufacturer was not bound by absurd tests on the one side, and by a specification which might suit one iron but would not suit another, and the sort of rail that was wanted was clearly stated, an excellent rail could now be produced for a fair price. A weight of 3 cwt. falling from a height of 20 feet on the rails was equal to an accumulated shock on the rails of 3 tons. Supposing the weight on a driving-wheel of a locomotive engine to be 7 tons, and that at a joint in the permanent way one rail stood $\frac{1}{4}$ of an inch above the adjoining one, then the velocity with which that would fall would accumulate a shock on the rail of $\frac{1}{7}$th of a ton, instead of 3 tons, as in the case of the falling weight. He thought, therefore, that such a falling weight was an absurd test. He did not deny that the dead-weight

test would give a certain result; but he was sure that almost any rail would amply support whatever weight might come on it as a dead weight. He did not agree with Captain Tyler that the form of the Vignoles rail was advantageous, because crystalline iron could be put where it was in compression and fibrous iron where it was in tension. That was very true if a rail was supported simply between two joints, but inasmuch as a rail was a continuous girder, in a certain position of the load the top of the rail was in tension and the bottom of the rail in compression; therefore if fibrous iron was required in one part it was required also in another. Yet rails were all so amply strong, that it was not a question of the strength of a rail, but of its durability. Iron rails should not be condemned because they wore out, but an attempt should be made to reform the rolling stock. The enormous weight put on the driving-wheels crushed the rails; and he thought conical wheels fixed to the axles should be discarded, as being very injurious to the rails: the better system would be to have every wheel revolving independently. Mr. Cross had tried this plan on the St. Helen's line with perfect success. He did not approve of the conical wheel, because, even if the wheels were revolving independently, one portion of the wheel-tyre must be sliding. Take the ordinary cone of the wheel, and the ordinary width of its bearing on the rail as only $\frac{3}{4}$ of an inch: then with a train of 100 tons moving at the rate of 20 miles an hour, there would be a grinding action equal to $1\frac{2}{3}$rd horse power; and if the train moved at the rate of 60 miles an hour, it would be equal to a grinding action of 5 horse power.[1] This must have a prejudicial effect on the wear of the rails. If they were simply subjected to a rolling motion, they would last for an indefinite period; and he was sure it was mainly due to the conical form of the wheels that the grinding and wearing motion took place: and this was increased by putting gravel and sand on the rails when they were at all greasy. He thought that steel tyres, which were now being adopted, working on steel rails lessened the adhesion, and

[1] The formula for this was—

$$\text{Horse-power} = \frac{w\,v\,b}{33{,}000\,f.\,n}\,\text{D}.$$

When w = total weight of train in lbs.

„ v = velocity of train in feet per minute.

„ b = breadth of surface of tyres in contact with the rail.

„ $\frac{1}{f}$ = coefficient of friction.

„ $\frac{1}{n}$ = degree of conicity of tyres.

„ D = diameter of wheel in feet.

that the weight on the driving-wheels would have to be increased. Therefore he maintained that wrought-iron rails should not be discarded. The proper course to pursue was to reform the rolling stock, to distribute the weight on a greater number of driving-wheels, to have wheels revolving independently, and to abolish the conical wheel.

Captain H. W. Tyler observed that Mr. Longridge had stated that it was necessary to provide for tensile strain in the top flange as well as the bottom flange of a rail. Now, in any case in which a weight was applied on each side of a sleeper, the top flange of the rail no doubt would be more or less in tension; but in reality and in practice the distance between the engine-wheels, and especially the driving-wheels, was at least 5 or 6 feet, while it was commonly more; whereas, the distance between the sleepers was only 2½ feet or 3 feet; therefore there could never be a weight supported on both sides of any sleeper at the same time. When the rails were sufficiently deep, and when the sleepers were sufficiently near together, the deflection of a rail under passing loads was imperceptible; and any strains which could be produced in tension on the upper flanges of the rails over the sleepers were practically immaterial, and were not to be compared to the strains in tension on the lower flanges between the sleepers.

Mr. John Boyd thought that if engineers abolished tests they would not get rails as good as those now obtained; although the falling-weight test was perhaps excessive at the present time. He did not think the mode of manufacturing rails had been sufficiently considered. It was certain, that by a proper mixture of iron in the puddling furnace a better rail could be obtained than by making use of any one quality of iron; for instance, by a mixture of Cumberland 'red short' hæmatite iron with Welsh iron, and also with Cleveland iron, both of which were 'cold short.' Sir Charles Fox once told him that he saw rails from England being delivered in America, and several of them broke when they were thrown down. He had formerly known the Scotch foreman who was superintending the delivery, and he said to him, "What a pity it is your Railway Companies don't give £1 a ton more, and get better rails than these." The reply was, "Weel, Sir Charles, they are just as guid as the bonds we gie for them." Before giving a judgment on the wear of the rails, it should be known how these rails which only lasted three or four years were paid for. If engineers did not specify the mode of manufacture, they should at least specify the description of iron of which the pile should be formed; and he would suggest that the top and bottom slab of the whole length and breadth of the pile should be formed of No. 2 hammered 'all mine-refined' iron, and the intermediate slabs of the whole length of the pile laid

so as to break joint, of puddled bars, and that the quantity of cinder in them should never exceed one-sixth of the whole burden on the furnace, and that no crop ends should be used, and the thickness of the slabs be so arranged that all parts of the pile should be reheated simultaneously.

He was of opinion that moderate, and particularly falling tests, should not be discontinued; and that care should be taken that the bulk of all the rails really were equal to the quality of the tested rails; as it was notorious that rails said to have stood the test stipulated for by the East Indian Railway Company's Engineer at the maker's works had not borne the same tests at Rotherhithe; and in his opinion the reputation of engineers and the safety of the public required that tests should not altogether be abolished.

He submitted the analysis of West Cumberland hæmatite Bessemer pig iron, which was extensively used by the makers of Bessemer steel throughout the kingdom for rails and other purposes. He advocated the use of a mild steel rail, as having most adhesion.

"Report upon the West Cumberland 'Bessemer' Pig Iron, by Dr. Noad, F.R.S.

"*Laboratory, Kinnerton Street, Dec. 10th*, 1867.

"Dear Sirs,

"I now have the pleasure of reporting on the last sample of Bessemer Iron which you sent me for analysis. I consider it to be first-rate iron; the quantity of silicon being by no means excessive, and sulphur and phosphorus wholly unimportant.

I am, dear Sirs,
Yours very faithfully,
(Signed) Henry M. Noad.

"*Messrs. West Cumberland Hæmatite Iron Co., Workington.*"

Analysis.

	per cent.
Graphite	3·850
Silicon	1·728
Sulphur	0·030
Phosphorus	0·044
Manganese	0·072
Titanic acid	0·152
Iron	94·124
	100·000

"Report upon the same, by Dr. Tosh.

"*Chemical Laboratory, Maryport, Dec. 9th*, 1867.

"The specimen of pig iron received on the 27th ult. has been found to have the following composition:—

		per cent.	
Carbon	as graphite	3·989	4·485
	combined	·496	
Silicon		1·767	
Sulphur		·608	
Phosphorus		·025	
Titanium		trace.	
Manganese		·219	
Iron		93·724	
		100·228	

"From the above results I have no hesitation in saying that this iron is of excellent quality.

"Considered with regard to its adaptability for Bessemer Steel making, it is in every respect one of the best irons which I have examined.

(Signed) Edmund G. Tosh, Ph.D.

"*Messrs. West Cumberland Hæmatite Iron Co., Workington.*"

Mr. F. D. Banister gave some details of the wear of rails on the Brighton Railway, and illustrated his remarks by a tabular statement. On the first $12\frac{3}{4}$ miles of the line from the London end towards Brighton, which carried the South Eastern and the Brighton main and local traffic, a length of 7 miles being a quadruple, and the remainder a double line, the total expenditure in rails for ten years, from 1856 to 1866, had been £20,865, or £159. 13*s.* 10*d.* per mile per annum; giving a per-centage on the original cost of £12·11, and showing a life of 8·10 years. In the suburban district, from Victoria to Norwood, on the West End and Crystal Palace line, the expenditure per mile per annum was £77; the total expenditure in ten years, £8,097; the per-centage of these on the original cost per mile per annum, £9·31, and the life of the rails 10·73 years. On the remainder of the main line, from Red Hill to Brighton, the expenditure per mile per annum was £72. 7*s.* 4*d.*; in ten years, £21,712; giving a per-centage of wear of £8·53 per mile per annum, and a life of 11·71 years. On the coast lines, Brighton to St. Leonards, and Brighton to Portsmouth, the results were nearly the same—expenditure, £40 per mile per annum; total expenditure, £15,000; and a per-centage of £4·94 per mile per annum on the original cost. There were some curious results on local lines. On the line between Wimbledon and Croydon the expenditure in rails in ten years had been £11. 6*s.* 8*d.* per mile; total expenditure, £511. On the coast line, from Lewes to Newhaven, which had been in use for twenty years, the expenditure for the last ten years had been only 14*s.* 10*d.* per mile per annum for rails. That showed that those rails were remarkably hard; they had worn very well, but more broken rails had been found there than on any other part of the system. The general result of the ten years' wear was an expenditure for rails of £78. 4*s.* 11*d.* per mile per annum,

LONDON, BRIGHTON, AND SOUTH COAST RAILWAY.

AVERAGE COST per MILE per ANNUM, and other Details respecting the MAINTENANCE of WAY and WORKS, for TEN YEARS ending 31st December, 1866, including RENEWALS both of WAY and BRIDGES, but exclusive of STATIONS and SIGNALS. Materials Net.

Length. Miles.	Length. Chains.	From.	To.	Wages. £. s. d.	Rails. £. s. d.	Sleepers. £. s. d.	Chairs, &c. £. s. d.	Renewal of Bridges. £. s. d.	Total. £. s. d.	Original Cost of Rails £7 5s., less Cr. for Old £3 12 6. Net Cost £3 12 6. £.	Amount expended in Rails in Ten Years. Net. £.	Life of Rails in Years.	In Ten Years' Wear of Rails, per cent. on Net Cost.	Tonnage per Annum.	Remarks.
12	65	B. Arms, Junc.	S. Nest. .	374 18 5	159 13 10	55 6 2	49 7 8	11 0 0	650 6 1	17,100	20,865	8·19	12·20	2,096,640	Seven miles quadruple, the remainder double line. Average speed 35 miles per hour.
29	60	Red Hill .	Brighton .	172 3 4	72 7 4	59 12 8	51 14 8	. .	355 18 0	25,436	21,712	11·71	8·53	898,560	Double line. Speed 35 miles per hour.
32	53	Brighton .	St. Leonard's	121 16 4	42 11 8	43 13 3	38 18 9	56 9 8	303 9 8	27,926	13,844	20·17	4·95	318,240	Ditto. Ditto 30 ditto.
41	43	Ditto . .	Portcreek .	105 1 10	38 0 6	50 14 3	38 10 0	44 9 6	276 16 1	35,514	15,966	22·24	4·49	555,440	Ditto. Ditto 30 ditto.
9	27	Croydon .	Epsom .	143 2 2	79 15 7	56 6 8	31 13 4	. .	310 17 9	7,983	7,169	11·13	8·98	861,120	Ditto. Ditto 30 ditto.
10	13	Norwood .	Victoria .	332 5 8	77 0 11	31 8 7	17 8 7	. .	458 3 9	6,688	8,097	10·73	9·31	3,781,920	Ditto. Ditto 30 ditto.
			Average .	208 4 7	78 4 11	49 10 3	37 18 10	18 13 2	392 11 10	. .	. .	14·03	8·07	1,418,653	
6	4	Croydon .	Wimbledon	67 0 0	8 10 0	11 6 8	6 13 4	. .	93 10 0	2,586	511	. .	. .	411,840	
9	9	Keymer .	Lewes . .	157 2 2	9 8 10	43 13 4	18 4 5	102 2 0	330 10 9	7,791	858	. .	. .	336,960	
5	47	Lewes .	Newhaven	103 9 1	0 14 10	37 16 4	10 10 10	79 5 5	231 16 6	4,777	48	. .	. .	299,520	

and a per-centage on the original cost of £8·07, the average maintenance of works over that portion was about £392. 11*s.* 10*d.* per mile; so that the per-centage for wear of rails upon the £392. 11*s.* 10*d.* was nearly 20, and the average life had been fourteen years. He might mention that between the Bridge over the Thames and the Victoria Station the rails originally laid by Mr. Fowler were of iron; they lasted two years, and had been twice renewed, but they had now been replaced by rails of steel. On a portion of the line near Bricklayers' Arms Station, in the summer of 1864 he had laid down 400 yards of steel rails, manufactured by Sir John Brown and Co. Over that portion on the down line the whole of the South Eastern and Brighton traffic had passed, being 16,500,000 tons, in three years and eight months. Those rails had been carefully measured, and he found that the wear had been a little more than $\frac{1}{16}$th of an inch. The iron rails adjoining were worn out in about sixteen months, with a traffic of about 6,000,000 tons, the speed in both cases being 30 miles an hour.

Mr. W. Bridges Adams observed that in the question of rail manufacture, the engineer was the designer of the form, strength, and quality required, if he were a veritable constructive engineer, while the manufacturer was the producer of what would sell and make most profit. The ironmaster preferred pigs, "the sow and pigs" in cast iron; next, heavy round bars, then square bars, then the section of a parallelogram, then the parallelogram channelled to make a rail; but improved forms he called fancy iron, and eschewed them, if he could, till a sufficient pressure was put upon him by the fear of losing trade. The quality prized in Bessemer rails was homogeneity. Whether they were steel or iron, was not a settled point. Mr. Bessemer himself did not decide whether they were steel or iron. Probably they were steel, from the fact of their breaking uncertainly, and, as shown by a sample on the table, the same bar breaking within a foot of the upper edge, where it was turned down under the engine-wheel as though it were a piece of lead. A good rough test for steel would be hardening and tempering a portion for a spring. Steel must be used either hardened and tempered equally, or annealed throughout. If neither of these processes were resorted to, it would be irregularly hard and soft, and would infallibly break. This was probably the reason why the maxim had grown up—"keep them soft." Bessemer rails in their best form were homogeneous iron, and would of course rub away under heavy friction, like any other homogeneous iron equally soft; but they would not laminate, as iron—not being homogeneous—was liable to do. Iron rails were made by what was called piling, *i. e.* iron in short lengths of differing quality, covered over with scale, everywhere except at the ends, where they were not intended to be united. These piles were full of hollow scale-cells, to which the air

got access while in the furnace, and when rolled out they were a mere series of fibres and ribands, separated by scale, in straight lines; and if farther rolled out, they would still be straight fibres, and not gnarled in curves like the grain of oak or elm, or like tinplate or sinuous iron, or like double thin steel, piled and curved and re-piled, or Damascus sword blades, or the original puddle bloom from the furnace. It seemed desirable with single-headed rails to obtain a hard granular top and a fibrous bottom to the rail, and it was possible to obtain blooms of those opposite qualities at the pleasure of the puddler. There was a process of uniting two such blooms without any scale between them, and therefore of rendering them homogeneous. They required to be flattened under the hammer into oblong slabs, with good surfaces and squared edges, and then to plane the two surfaces which were to be united to a close fit. Placed together, and heated in the furnace to a welding heat, they would roll out homogeneously. But when the best rails were produced, the question arose as to the most judicious mode of applying them in line. A sample rail of the bridge form from the South Wales line, after being down for many years, appeared as good as ever. But it had been laid on a continuous longitudinal timber, and was boarded on the top, to make the iron cross the fibres of the wood; for it had been found in practice that with the rails parallel to the fibres the longitudinal logs split. The rail was perfectly granular, and had it been used with intermediate chairs, it would probably have broken. Chairs formed anvils to rails, and notched them below while they were bruised above by the wheels. Neither had fish-joints yet been perfected. Some elasticity must be given, not positive play, but a vibratory elasticity, and a true joint connection.

Increased speeds had to be provided for, multiplied three-fold for 7 and 8 tons' load on each driving-wheel, instead of two, and for increased length of wheel-base growing from 7 feet and 8 feet to 16 feet and 30 feet, and constantly increasing curves on the lines of rails. In short, long rigid parallelograms were being driven round very sharp curves, the wheels at a tangent with the rails. What the amount of grinding was might be gathered from the reversal of a double-headed rail. It at first presented a series of square-edged notches, $\frac{1}{2}$ inch deep: at the end of a week the edges were taken off; in another week the metals became small curves, then large curves, and gradually the rail became a level plane. If the wheels rolled instead of sliding, they would simply roll over the curved surfaces; but as they slid, they became a planing-machine, and cut off the projecting metal. To get rid of the friction, it was necessary first to radiate the axles so that the wheels would always be in parallel planes to the rails, whether on straight lines or on curves, or double

reverse curves. Then to form the carriages with curved spring-ends instead of side-buffer rods, to use short openings between the vehicles, closing the trains to lessen resistance, and prevent the vehicles riding on each other's backs in collision, to use continuous breaks, self-acting by gravitation, like steelyard levers—the normal condition to be pressing against the wheels, lifted by guard or driver, and instantaneously in action on inclines, in case of a coupling breaking. When these things were done, the engine-power might be reduced, and the weight of the engines or the load of the train might be increased. Tank engines were used, because they could run with either end forward. Tender engines, if properly coupled, making one bending machine of engine and tender, would do the same. At present, in order to obviate a vicious design, the driver screwed up the engine and tender rigidly together; and a long stiff body was thus formed, which was apt to get off the line, and which indeed would not keep on at all but for its weight. The question of light engines and vehicles was important; but when the surplus resistance was removed the trains might be lightened. Light trains should be used for light branch traffic; but with traffic unlimited, the loads on the engine driving-wheels should be what the rails and lines would bear without being crushed, and the train-capacity should be in conformity. If tank-engines were used for long journeys, the load of water, which was a diminishing load, should not be placed near the driving-wheels, but as far away as possible. Any tender-engines could be altered to run tender foremost as steadily as a tank-engine; and two engines could be efficiently coupled together to work as twins, with water-tanks for short distances, without injuring lines or rails.[1]

Mr. E. A. Cowper had prepared a Table showing roughly the different modes of manufacturing steel and iron, simply for quick comparison of the number of operations in each of the processes. In the old practice the iron used always to be refined before being puddled, but that process was now generally omitted, from economical motives, though he was afraid in some cases it was but false economy, and that the frequent very short life of a rail was partly due to it.

According to the old process for making steel there was of course the cementing, the melting in pots, the hammering the ingots, and the rolling, in addition to the refining and puddling. The melting of steel in quantities of about 40 lbs. each in separate pots was a most expensive process, the wear and tear of the furnace on such small quantities was very great, and it was therefore impossible to make cheap steel rails on that plan, though it was admirable

[1] *Vide* "Railway Practice and Railway Possibilities," by W. Bridges Adams, London, 1868.

for tool-steel and other expensive kinds. He had put Lowmoor as the name of a process, although it was practised at other places.

TABLE showing the Number of Operations in each of the Various Processes for Making IRON and STEEL.

	Old Practice.	Modern Practice.	Lowmoor.	Marshall.	Krupp.	Bessemer.	Siemens.	
							Scrap.	Ore.
IRON.	Smelting. **Refining.**	Smelting.	Smelting.	Smelting. Refining.		Smelting. **Melting in Air Furnace. Blowing in Converter.**	Smelting.	**Melting in open Hearth.**
	Puddling.	Puddling.	Puddling H. I.	Puddling.			Puddling.	
	Hammering Balls.	Hammering or Squeezing Balls.	Hammering. **Breaking and Selecting.**	Hammering Balls.		Hammering Ingots.	Hammering Balls.	
	Rolling P. B.	Rolling P. B.		Rolling P. B. **Cleaning.**			Rolling P. B.	
	Piling.	Piling.	Piling. Hammering.	Piling.				
	Rolling.	Rolling.	Rolling.	Rolling.		Rolling.	**Melting in open Hearth. Examining.** Hammering Ingots. Rolling.	**Examining.** Hammering Ingots. Rolling.
STEEL.	Cementing.				Smelting. Puddling. Rolling. **Hardening. Breaking and Selecting.**	Same as above.	Same as above.	Same as above.
	Melting in Pots.	**Melting Cast and Wrought Iron in Pots.**			**Melting in Pots.**			
	Hammering Ingots. Rolling.	Hammering Ingots. Rolling.			Hammering Ingots. Rolling.			

The pigs were first taken and puddled to produce hard iron—iron with about ·15 per cent. of carbon in it; the ball was then hammered thoroughly into a thick flat cake; it was not rolled at the same heat, but it was thrown on one side to cool. It was then broken up and selected, and he believed that the process of examining each piece and selecting the iron was one of the causes why it had won such an excellent name for tyres and for other things where iron was required to be hard. By these means it was known that every part was hard; there was no question of one puddler bringing out a soft ball and another a hard one, and the iron being all mixed or 'piebald.'

Then came what was commonly called the 'Marshall' process. In this there was the smelting, the refining, the puddling, the hammering the balls, and the rolling the puddle-bars; then the 'cleaning' of the iron, which was a species of 'milling,' and consisted in putting the small pieces of iron, cut into short lengths, into a cylinder, with a quantity of sand and water, and turning them round and round until they were thoroughly cleansed from all black scale: afterwards this bright iron was piled and rolled, and 'blacks' in the iron were thus avoided.

In Krupp's process of making steel the metal was first puddled, then rolled into bars about 0·9 inch or 1·0 inch square, and thrown into cold water, which of course hardened the steel from end to end. It was then broken up into short lengths, so that every piece of 3 cubic inches was examined at both ends, and it was examined and selected according to quality. The pieces were then put, like the cemented steel, into pots, melted, cast into ingots, hammered, and rolled. A sort of military discipline was exercised in bringing the men with the melted steel in the pots up to the bath, or pond of metal, by the sound of a bugle; and sometimes more than a hundred pots full of steel were got together for one cast. Krupp, however, now used Bessemer steel largely; and he had many Bessemer converters at work, although he did not exhibit any steel at the Paris Exhibition by the name of Bessemer steel. Much depended upon the manganese and other ingredients put into the pots with the steel in this as well as in other places.

In the Bessemer process there was the smelting the pigs, the melting, the blowing, the casting, the hammering, and the rolling. The blowing was the chief process, and by it either wrought iron or steel of various degrees of hardness could be produced. The use of a certain quantity of spiegeleisen was of great importance.

Last on the Table were Mr. Siemens' two processes. In the first plan for making steel, from puddled bars or scrap iron and cast iron, the wrought iron, having of course been smelted, puddled, hammered, and rolled, was simply melted down in a bath of melted cast iron, in the hearth of a furnace having an intense heat, but no

oxidizing flame, and the ingots were cast from this large bath of melted metal.

In Mr. Siemens' second plan the iron ore was brought into a state of 'sponge of iron' by the heat to which it was subjected in a non-oxidizing atmosphere, or one in which some carbon was present, though not enough to convert it into cast iron: the iron was not in any way exposed to a 'cutting flame' or 'burnt,' but the drops of metal were absorbed, or, so to speak, dissolved out of the 'sponge of iron' by the small quantity of melted cast iron at the bottom of the hearth. There was, therefore, in this process only the melting, examining, the hammering into ingots, and the rolling; thus by either the first or second process there was obtained a perfectly homogeneous cast steel, or wrought iron, without any blacks or bad welds caused by piling or lapping up of cinder in the ball, as in puddling.

He thought Mr. Bessemer was quite right when he, some years ago, said that no perfect metal could be produced without its being melted; and now there was a furnace that produced such an intense heat, that tons of steel or wrought iron could be as perfectly melted as the little drops of steel of 40 lbs. weight were in the steel pot-furnace of former days, and yet without any burning of the iron or steel. He thought each of the processes named in the table depended greatly for its success on some one point being attended to. Thus, in the old process, 'refining' was of great use in preparing pure 'plate-metal' before puddling; while the practice of 'breaking and selecting' in the Lowmoor and Krupp processes was admirable. The old plan of melting in pots was, and still continued to be, a very expensive process; whereas the Bessemer plan not only made steel and wrought iron very direct from cast iron, but gave the power of casting large ingots cheaply, though without the means of examining the metal in the process. In Mr. Siemens' plan there was certainly the advantage of being able to examine and test the metal under operation, and either to increase or diminish the quantity of carbon, so as to make 'high' or 'low' steel or wrought-iron at pleasure; and from the casting of such large quantities of metal at a time, and the economy of fuel in the furnace, excellent metal could be turned out very cheaply.

Mr. F. Stileman stated, through the Secretary, that the total annual cost for maintenance and renewal of the permanent way of railways was above 9 per cent. of their gross receipt, and in the year 1866 amounted to £3,466,668. This expenditure showed an increase of £507,709, or 21·6 per cent. over the expenditure of the year 1863, the increased mileage for the same period being 13·22 per cent.

The estimated tonnage of rails laid in main lines was 2,438,520 tons: taking the life of iron at ten years, it would require 243,852

tons, at a cost of £7 per ton, equal to £1,706,964 to be expended annually; if renewed with steel rails, lasting double the time, 121,926 tons would be required at £11 per ton, equal to £1,341,186, showing a saving of £366,778 per annum, or nearly 1 per cent. of the gross railway receipts.

Mr. Brunlees observed, through the Secretary, that the rails on main lines were, generally speaking, more deficient in bearing surface than in quality. Their tops were too narrow for the weight of engines now employed, hence they became laminated, and were crushed long before they were worn out. If rails were made with a top double the present width, or of the same width as the tyres of the wheels, the crushing power of the wheel thus diffused would be reduced to one-half, consequently the life of a rail would be doubled. To make such a rail, a weight of about 30 lbs. per yard would have to be added to the 80 lb. rail; but the additional cost would only amount to one-third of the additional cost of laying down steel rails at 80 lbs. per yard. He had, therefore, no hesitation in saying that the saving which a wider topped rail would effect in the wear of tyres would alone very shortly pay for the additional weight of metal; whereas, if steel rails with only the ordinary width of head were used, the wear of tyres would be considerably accelerated. To maintain a good line, and a fair top on the rails, more lateral strength was required, and this would be gained in the wider rails. There would also be a considerable saving in maintenance, and that sometimes oscillating, sometimes trembling motion, due to the weakness of the road and the wear of the tyres, would be completely done away with. No doubt there were special places where steel rails might be used with advantage, but, generally speaking, iron rails of good quality and of greater section, combined with a judicious distribution of the weight on the locomotive wheels, would meet a greater number of present desiderata than could be supplied by the use of steel.

Mr. Joseph Mitchell expressed his opinion, through the President, that the flat-bottomed form of rail might be the best, if of steel, laid irrespective of expense, on a continuous bearing: but he doubted the superiority of that form of rail when laid on cross-sleepers, for it thus became, in fact, a girder between two points 3 feet apart.

It was inferior as such to the double-headed rail, as it had less depth, being for a rail weighing 75 lbs. per yard about $4\frac{1}{4}$ inches in depth; whereas the double-headed rail was generally $5\frac{1}{4}$ inches deep, and was formed like a girder, with its effective strength on the upper and lower sides; the cross bearing also was only 5 inches, as compared with the bearing of the chair, which was 10 inches.

If the flat-bottomed rail was made higher than $4\frac{1}{2}$ inches, it was apt to deflect with the weight of the trains. No doubt

it was the cheapest, but not much, the saving not exceeding £70 per mile.

Although the double-headed rail, with its numerous fastenings, still required improvement, yet, in practice, it had been found to be the best, or it would not have been continuously relaid, and otherwise so universally adopted by all the principal engineers throughout the kingdom up to this time.

Again, good ballast was an important element in securing a sound and cheap permanent way. If a line was not well ballasted and the ballast of good material, the rails would never wear equally, however superior might be the quality of the iron. If the ballast was soft or clayey, the pressure of the trains would make the rails sink in wet weather, and thus create irregularities which, with the repeated concussion of the engines, tended much to destroy and damage them. Now, on a large portion of the railways he had made in Scotland, extending over 280 miles, not only was there good gravel ballast, but the embankments and cuttings were mostly gravel. The consequence was that the motion of the trains was so smooth and easy as to be a matter of general remark. The rails on the first section opened, which were double-headed, had been down thirteen years, and he had no doubt they would last six years longer.

He thought sufficient data had not been obtained to afford a satisfactory conclusion on this subject, and he suggested that permanent-way Engineers might be asked to divide the lines under their charge into sections of 10, 20, or 30 miles, or such other distances as were subject to similar traffic; and to report on the nature of the ballast, the size of the sleepers, the form and weight of the rails—and, if possible, the makers' names, the average number of trains, and the average tonnage passing over those sections per annum; also the quantity and cost of ballast per mile, the cost of wages per mile, and the number of sleepers and rails renewed in each year.

By a return of this nature, an accurate estimate of the cost of the maintenance of permanent way under every variety of circumstances, might be obtained, and thus proprietors of railways might know, by comparing the maintenance of one railway with another, whether those they were interested in were maintained in the condition and at the expense they ought to be.

Mr. J. M. Heppel suggested, through the President, that rails should be tested directly for durability. Suppose, for example, a pair of rails 10 feet long to be laid down, and a pair of wheels carrying 10 tons to be kept, by a small fixed engine with a crank motion, continually rolling backwards and forwards over them till they exhibited symptoms of failure. It seemed to him that this would nearly represent the actual condition under which the

wear and tear took place; and at any rate, as a comparative test between different specimens, would give very useful information. In this way in about a month an amount of tonnage might be passed over equal to that by which the best rails were worn out. No doubt the tendency of such a test would be to stimulate the production of hardness at the expense of ductility; and to counteract this, some test for the latter, such as a blow from a falling weight, would have to be added.

He thought that if manufacturers were requested to tender on their own specifications, but guaranteeing a certain resistance to impact, and a certain tonnage passed over at a given speed, in the way just mentioned, all their special experience would be utilized, and there would be a considerable amount of security for the result.

He was aware that some difficulty would arise in submitting to test a sufficient number of specimens without undue expenditure of time and money. Still it might be managed; and if the results to be expected were as valuable as they appeared to him likely to be, a considerable outlay in obtaining them would be well repaid.

Mr. W. M. Neilson suggested, through the President, that rails should not be tested at the works of the makers, but at a public testing-machine, under responsible management, to which rails might be sent for undergoing the test process. Experience would give those who managed this machine facilities for discovering the different qualities of rail submitted to them. Suppose four rails to be tested together, by four wheels hooped with ordinary tyres, suspended by a lever pendulum frame, the wheels to be loaded to the required weight, and so carried by a spring as to give such a shock to the rails as might be found desirable. The lower end of the lever, by touching projections in its motion, would cause the side oscillating motion: and the amount of adhesion might be measured by buffer springs at the ends of each of the rails. A simple attachment to a small steam engine would give the requisite motion to the machine, which would, of course, be kept constantly at work; the number of oscillations and pressures on the buffer springs being recorded by a tell-tale.

The motion of the wheels round the axis might be regulated by springs or weights, suspended by chains leading from pulleys over the centre of the pendulum frame; but the reverse motion of the wheels might not be a too severe element in the test.

Mr. Sandberg said the discussion had been such as to render any reply on his part almost unnecessary. However, he should like to direct attention, first to the steel-headed rails, and next to the Annuity Tables. His object in alluding to the steel-headed rails arose from the difficulty which existed in foreign countries in usefully employing the worn-out iron rails. In countries round the

Baltic and the Mediterranean, they had been re-rolled with iron slabs, but of late Bessemer steel had been applied for the heads. He never expected to obtain perfect homogeneity, nor to get the same wear out of the steel-headed as out of the solid steel rails; and, therefore, in the Annuity Tables the former were represented as lasting only half as long as the latter. If the worn-out iron rails could be converted into solid steel rails by Mr. Siemens' plan, it would certainly be a great advantage for railways, not only in this country, but in the colonies and indeed wherever far removed from the seat of manufacture. These steel rails would, of course, have to be equal to the Bessemer rails in quality and price; and if Mr. Siemens could succeed in making them as cheap and of equally good quality, he would not for a moment continue to defend steel-headed rails.

As to the Annuity Tables, some objection had been made to the eighty years taken as the life of solid steel rails. According to his view, compound interest was an important feature in arriving at a just comparison between the values of the three descriptions of rail, and he had no other means of expressing their relative capacities of enduring wear than by giving their life in years. He thought that sufficient experience had been adduced in this discussion from different railways to prove that solid steel rails lasted on an average six times as long as common iron rails, though he admitted that iron rails could be made of a quality far superior to that usually employed; but in such a case they might cost more than steel rails; and therefore in the comparison he had made he had taken common iron rails, without extra price, or any guarantee, or extra specification. There had been fifty instances mentioned on the London and North Western Railway, where solid steel rails had lasted six times as long as iron rails; instances of the same kind had been stated on the London, Chatham, and Dover Railway; and on the North London, in about forty instances, as far as their experience had extended up to the present time, steel rails had lasted four or five times as long as iron rails. All these steel rails were still in use, and in good condition. As regarded steel-headed rails, he had received a favourable statement from the North British Railway; and that day he had heard from Mr. Ashcroft that some of those rails made for the Swedish Government referred to in the Paper (Plan B, Plate 14), and described in the discussion by Mr. Menelaus, had been laid a few months on the South Eastern Railway at London Bridge Station. Mr. Ashcroft had given a very favourable report concerning them. However, more experience was needed to prove that they would last three times as long as common iron rails.[1]

[1] Mr. Ashcroft has stated in a letter to the Author, dated May 18th, 1869, that trains computed to have weighed upwards of fifteen millions of tons had passed over the steel-headed rails between March, 1868, and May, 1869. These rails were laid in the London Bridge yard of the South Eastern Railway, and he had been sur-

Mr. Bell had expressed a fear as to the supply of pig iron for the future make of Bessemer rails. The same opinion was entertained by the Swedes five or six years ago, when the Bessemer process was introduced. They had actually tried to prove that nothing could be done without Swedish ore. However, very little of the Swedish pig-iron which had come over to this country had been employed for Bessemer steel rails; and there was no doubt that the English hæmatite would be sufficient for some time to come.

With regard to the statement that the pig iron made from Norwegian ore at Newcastle contained 0·5 per cent. of phosphorus, Mr. Bell had admitted that the statement applied to ore from a lately-opened mine, and that it was not applicable to the great bulk of Norwegian ore. His own opinion was, that if the English hæmatite ore should not prove plentiful enough, the ores from Sweden, Norway, Bilboa, Elba, and America, were sufficient to provide for any future want of pig iron for the Bessemer process.

As to the tests of iron rails, very few Railway Companies had adopted any more severe than those Governments with which he was connected: that had arisen from the severe climate in the Scandinavian countries, the ground being often frozen 3 or 4 feet deep, and offering in winter little or no elasticity. The speed had to be reduced considerably in the winter, to save both the road and the rolling stock. Although it was well known that greater wear could be obtained from rails containing a large per-centage of phosphorus, such as those from the Cleveland district; yet the greater strength, and consequent safety, of the Welsh iron had been taken into consideration, and most of the supply for Scandinavia had been procured from the Welsh districts. There had been no breakages of rails on the Swedish lines, but the Russians had during the severe frost of 1866 a great number of rails broken; the number amounting to two hundred a week during the most severe part of the winter. These Russian rails had been made in this country, nearly of the same section (Vignoles') and weight as the Swedish rails; but the test for the rails destined for Russia was only half as severe as that for the rails for Sweden, the latter being a 15-cwt. ball falling 7 feet on the rail, supported on bearings 4 feet apart.

The statement that steel rails in Canada were not injuriously affected by cold so much as iron rails, was what might have been expected. Steel was less subject to the influence of cold than iron,

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prised to find that they had resisted so perfectly, (there being no apparent failure whatever in them,) when it was considered that they weighed only 66 lbs. per yard. Opposite to these rails there had been laid some iron rails, weighing 82 lbs. per yard, manufactured by an eminent firm; the latter exhibited evident signs of early failure. It should be noted that all these rails were laid on a curve and on a gradient of 1 in 100, and where the breaks of every train were applied to stop at the platform.

especially when phosphorus was present in the iron. But steel rails had broken when the weather was temperate, in ordinary wear, and even in unloading from the trucks, as had been remarked by several speakers. These rails had been examined, and in the generality of cases they had been found to contain too much carbon. Still there had been several cases in which steel rails had been broken, without being too hard, or containing too much carbon, but from excess of silicon. Formerly it was believed that the silicon was eliminated in the Bessemer process before the carbon was carried off, forming a cinder, which acted on the carbon in the same way as in the puddling furnace. There was now reason to believe that, where there was much silicon present, and very little carbon, the latter disappeared before the silicon, and some silicon was left which rendered the steel brittle. Steel rails had been broken on the Belgian State Railway, and, when they were analysed, there was found to be no excess of carbon, but so large an amount of silicon as 0·6 per cent. In another instance as much silicon as carbon had been found in the metal. These facts had been confirmed by Director P. Tunner, of Vienna, who had communicated the fact to Dr. Percy in a letter, from which he had the privilege of reading the following extract:—

"At the iron-works at Neuberg, in Styria, the Bessemer metal is carefully assorted after every cast, and is separated into seven series, or different degrees of hardness. The brands to be marked are ascertained on the one hand mechanically, by welding, working, and hardening, by the tensile strength and elasticity; and, on the other hand, chemically, by the Eggertz carburation process: it is only when the same result is obtained by these two methods that the numbers denoting the degree of hardness are marked. A very great difference has been ascertained between the results of the mechanical and those of the chemical methods, in the quality of some Bessemer steel, which was made about eight days ago from pig-iron made by charcoal with ¼th its weight of coke. By the first method No. 3 was indicated, that is to say, a very hard steel difficult to weld, but otherwise of good quality. By the other test it proved to be No. 6, that is to say, it had a hardness next to that of wrought iron. In consequence of this very remarkable difference a chemical analysis became necessary, which showed that the steel in question contained only 0·3 per cent. of carbon, but 1·0 per cent. of silicon. It therefore appeared that silicon might occur in steel as a substitute for carbon, and it is particularly remarkable, that it was found in a hard steel. This fact further proves that it is not always true that by the Bessemer process the silicon is first eliminated, and then the carbon. That some proportion of silicon may exist in steel has been long known; and Schafheutl maintains that some silicon is a necessary constituent of steel. But that with 1·0 per cent. of silicon and only 0·3 per cent. of carbon, it is possible to obtain a hard steel, seems to be a new observation worthy of attention."

This confirmed what had been lately found in this country, namely, that the silicon and carbon disappeared simultaneously, and not, as was formerly believed, the carbon first and the silicon afterwards. Therefore, as an excess of silicon had the same influence on the hardness of the steel as an excess of carbon had, and as the

amount of the former was more difficult to regulate in the process of steel-converting than the latter, which could be judged of by the flame, he thought it might be concluded that, until further experience was gained, Bessemer rails would require to be as carefully tested as those made from iron. In concluding his remarks, Mr. Sandberg took the opportunity of thanking those gentlemen who had taken part in this discussion, for the valuable information which they had brought forward. That information formed a most useful contribution to the knowledge of the manufacture and wear of rails, and would doubtless tend greatly to the benefit of both the manufacturer and the consumer.

Mr. Gregory, President, said it must be pleasing to the Members of the Institution to find light thrown upon professional subjects, not only by different minds but by different nationalities. The last subject under consideration was a Paper by an American Member. The Paper that had now been read was from a Scandinavian Member of the Institution, and he was sure all who had heard it would agree that it was one which merited the thanks of the Institution.

Note by the Author.

Since the foregoing Paper was read, the price of steel rails has been reduced beyond expectation. At the present time (June, 1869) the cost of solid steel rails, at one of the principal works in this country where both kinds of rail are made, is £10 per ton as against £7 for iron rails. As Mr. Bessemer's patent will expire next year, the reduction of the royalty now paid, will gradually have the effect of bringing the price of steel rails nearer to that of iron rails; but it seems doubtful whether any sudden reduction of price will ensue. Under these circumstances there can be no doubt as to the expediency of employing steel rails, even on railways where the traffic is light; but, of course, the heavier the traffic the greater will be the economy of substituting steel for iron.

During the last twenty years the price of iron rails has been gradually reduced to one-third of their original cost, but this reduction has unfortunately been accompanied by the production of an inferior quality of rail—a subject alluded to by several speakers in the discussion. It is to be feared that to some extent a similar effect may possibly follow the anticipated reduction in the price of Bessemer rails; and it will therefore become more than ever necessary, for the public safety, that the consumer should carefully examine the quality of the material which he receives.

March 10 and 17, 1868.

CHARLES HUTTON GREGORY, President,

in the Chair.

The discussion upon the Paper, No. 1,196, "On the Manufacture and Wear of Rails," was continued throughout these meetings, to the exclusion of any other subject.

March 31, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,198.—"The City Terminus Extension of the Charing Cross Railway." By JOHN WOLFE BARRY, M. Inst. C.E.

THIS extension of the Charing Cross Railway was projected with two objects in view; first, to give to the whole of the districts served by the South Eastern Railway Company direct access to the heart of the City, and, secondly, to form a Metropolitan connecting link between Charing Cross at the West End and Cannon Street at the East, accommodating by this means the important traffic constantly passing to and fro between these two central points. (Plate XV., Map.) The convenience afforded to the public may be gathered from the fact that, during the year ending the 1st of January, 1868, being the first year after the railway was opened to Cannon Street, about eight millions of passengers used the Cannon Street Station, of which number about three and a half millions were local passengers booked between Cannon Street and Charing Cross. At the present time about twenty-six thousand passengers use the station daily, and this number may be expected to increase, especially so far as regards the City and West End traffic.

The works comprised under the above title were authorized by Act of Parliament, dated June 28th, 1861, and consist, in the order which this description will follow, of

(1.) The Bridge over the River Thames.
(2.) The Cannon Street Station.
(3.) The Viaducts south of the River Thames, connecting the Thames Bridge with the main line of the Charing Cross Railway.

The whole of the works were designed by Mr. Hawkshaw (Past-President Inst. C.E.), the consulting Engineer to the South Eastern Railway Company, and were carried out under his direction, the Author being the Resident Engineer for almost the whole period of construction. Mr. George Wythes (Assoc. Inst. C.E.) was the contractor for the whole work; but the ironwork generally, together with the erection of the bridge over the River Thames (excepting the abutments), was sublet by Mr. Wythes to Messrs. Cochrane, Grove, and Co., of Dudley. Messrs. Cochrane's

works were directed by Mr. Joseph Phillips (Assoc. Inst. C.E.), and Mr. Wythes was represented by his agent, Mr. William Canning. The works were commenced in July, 1863, and the Railway was opened for public traffic on the 1st of September, 1866. Considerable difficulty, involving delay, was at first experienced in obtaining possession of the land, as is often the case in the Metropolis, and the works were further retarded by the requirements of the Thames Conservancy Board, who would not allow more than a certain number of the piers of the bridge over the river to be in progress at one time.

THE BRIDGE OVER THE RIVER THAMES.

(Plates 15 and 16.)

The bridge has been constructed to carry five lines of way from the south abutment to the pier next to the Middlesex shore, at which point the five lines branch out on the part of the bridge which is termed the Fan, and are connected with the nine lines of way which are in the station. There are two footpaths, with approaches and toll-houses, one on each side of the bridge, fenced off from the portion devoted to railway purposes. They were intended for the use of the public on payment of a small toll, and would no doubt relieve the crowded condition of London Bridge. They were completed at the same time as the railway, but have not yet been opened for traffic.

The extreme length of the bridge between the abutments is 706 feet. This length is divided into five spans, measuring from centre to centre of the piers as under, the clear spans being also given:—(Fig. 1)

	From centre of Pier to face of Abutment on Centre Line.	Clear space on Centre Line.
Two side openings	131 feet	125 feet.
	From centre to centre of Piers.	
Three centre openings	148 feet	136 feet.

The width of the straight portion of the bridge outside the footway parapets is 80 feet, and the width of the railway portion between the inside parapets is 61 feet 8 inches. (Fig. 2.) The Fan, which extends over the Middlesex opening, is widened out from an extreme width of 80 feet at the Middlesex pier to 202 feet at the north or Middlesex abutment, and accommodates, in addition to the lines of way, portions of two passenger platforms, engine sidings, and foreman's offices, &c. The height of the soffit of the bridge above Trinity high-water level varies from 24 feet 8 inches at the abutments to 25 feet 4 inches in the centre span. The top of the pier next the shore on each side is 4 inches higher than the abut-

ment, and the top of the two centre piers is again 4 inches higher than that of the side piers. The object of this arrangement was to prevent the bridge appearing depressed at the centre. The height of the rails above the soffit of the bridge is 9 feet 10 inches. The greatest depth of water at low water was about 13 feet 6 inches, and the difference between Trinity high water and low water is 18 feet.

The Abutments.

The southern abutment is advanced about 40 feet into the river beyond the general line of wharf frontage. The ground on which it was necessary to build is London clay, lying beneath a depth of about 15 feet of river mud and alluvial deposit. It was decided to build this abutment on cast-iron caissons. This arrangement had the advantage 'inter alia' of rendering a coffer-dam unnecessary. The size of the caissons, which are square on plan, with rounded corners, is 12 feet by 12 feet. The total height of the caissons is 18 feet; they are divided into three lengths, each length consisting of eight pieces, and being 6 feet high. The size of the large plates is 6 feet by 8 feet, and the thickness of the metal is $1\frac{5}{16}$ inch. The caissons were sunk side by side without any great difficulty, partly by means of divers working in helmets, and partly by dredging inside the caissons with a bag and spoon dredger. The square form of the caissons is not, in the Author's opinion, desirable where cylinders can be conveniently employed. Considerably more difficulty was experienced in keeping the caissons vertical than was the case with the cylinders, and they are weaker, in proportion to the weight of metal employed, than a cylinder enclosing the same area. The caissons were sunk to a depth of 36 feet below Trinity high-water level, the tops being 18 feet below the same datum. York landings were placed on the caissons, and on these brickwork in Portland cement was built up to the level of the bed stones for the girders of the bridge, a height of 42 feet. The north abutment was built without either caissons or coffer-dam; lengths of ground about 30 feet long and 22 feet wide were excavated at low water; a 'stank' dam of clay was employed, and the length opened being short, the water which came into the excavation at flood tide was quickly pumped out by a steam pump as the tide ebbed, and a strong force of men was employed to continue the excavation, or get in the footings, before the tide returned. The depth of the bottom of the footings of this abutment below Trinity high-water is 21 feet 6 inches. The bottom is gravel of excellent quality; the brickwork is built with Portland cement from the bottom to a height of 7 feet above Trinity high water, from which level it is built with ordinary grey lime mortar. The

thickness of the south abutment is 12 feet, and of the north abutment 16 feet. The facing of both is red brick, and the plinth, quoin, arch, and string stones are of Bramley Fall.

The Staging for the Bridge.

The Conservators of the river would not allow more than two piers to be in progress, or more than two openings to be impeded by staging at one time, and stipulated that in each span a water way of 50 feet should be left in the staging for the passage of craft. These conditions naturally delayed the progress of the works considerably; but the traffic at this narrow part of the Thames is so heavy, that any other arrangement would have greatly inconvenienced the public traffic of the river. The staging for the piers was first erected of a width only sufficient for a berth for a barge on each side of the cylinders, with platforms for unloading materials, and as the piers were finished, it was widened out on each side, so as to contract the opening to 50 feet. This was spanned by a timber truss, and a continuous platform was thus formed over each span for the erection of the girders. Great difficulty was experienced in erecting the staging and keeping it in order; and especially in driving the first few piles for each pier. The strength of the tide at this narrow part of the river is great, and the craft, which are very numerous, were continually swept up against the pile barge and the first few piles which had been driven, occasionally carrying away everything before them. In this way the staging for some of the piers was three times commenced, and as often swept away, before it could be made sufficiently strong to resist the attacks of the barges.

The Piers.

(Figs. 2 to 6.)

The piers are each formed of four cast-iron cylinders, placed in a line at right angles to the longitudinal axis of the bridge, and connected by two wrought-iron transverse girders at the top. The cylinders are for the most part alike, except that the depth to which they are carried varies slightly. The description of one will therefore suffice for all. The outside diameter of the cylinders is 18 feet below and 12 feet above the bottom of the river. A conical reducing ring is introduced, to effect the junction between the two diameters. The cylinder plates are fluted from 5 feet below Trinity high-water mark up to the level of the ornamental cap mouldings. The ordinary rings of the 18-feet cylinders are 9 feet high, and each ring consists of nine segments, which are 6·28 feet measured round the arc. The thickness of the metal generally is $1\frac{1}{2}$ inch. The flanges are from $3\frac{1}{2}$ inches to 5 inches wide, and $1\frac{1}{2}$ inch thick.

The 12-feet cylinder rings, which are each also 9 feet high, below the fluted portions, are formed in a similar way of six segments, each segment being as above, 6·28 feet measured round the arc. The thickness of the metal is 2 inches. The fluted rings consist also of six segments, which are considerably stronger and heavier than the others. The reducing ring is formed of nine segments, which are 9 feet high, measured vertically. The metal in the reducing rings is 2 inches thick throughout. The bottom ring of cylinder plates is only 4½ feet high, and is of extra strength, with a sharp-cutting bottom edge; the thickness of metal in this ring is 2½ inches. Figs. 2 to 6 show further details of the cylinders. In order that the fluting should begin at the same level in all the cylinders, a special ring of plates was necessary for each cylinder, it being impossible to sink the cylinders with sufficient accuracy to keep the tops of all of them level with one another; and the subsidence under the test load was not always uniform. This special length was cast after the testing was completed.

Sinking the Cylinders.

The cylinders were sunk as follows: The bed of the river was smoothed by dredging on the site which the cylinders were to occupy. The two bottom rings, making a height of 13½ feet, which was equivalent to the greatest depth of water, were built up and caulked over their destined position, resting on timbers and between strong timber guides. The cylinder was then raised by a travelling crane so as to permit of the removal of the supporting timbers, and was afterwards lowered into its position on the bottom of the river; a third ring of plates was next added on the top of the other two rings, and a bag and spoon dredger was worked inside the cylinder. The ground lying over the London clay, consisting of mud and gravel, was by this means taken out and removed in barges, and additional rings of plates being bolted on as the cylinder descended, it was thus sunk through the superincumbent strata until the London clay was reached; the water was then pumped out and the sinking continued by ordinary excavation until the final depth was attained, which was from 59 feet to 65½ feet below Trinity high water. The sinking of some of the caissons and cylinders through the mud and gravel was, when the works first commenced, carried on by divers working in helmets, but after a short time the dredging with the bag and spoon was adopted, and found to answer its purpose, in many ways, better than the divers. Concrete in Portland cement was put in on the London clay in layers of from 4 feet to 5 feet up to the level of the bottom of the reducing ring, and brickwork of pavior bricks laid in Portland cement was built on the concrete up to the level of 2 feet above low-water mark,

where the erection of the cylinders was stopped for testing. The testing, which will be described hereafter, having been finished, the building of the cylinder was continued in the same manner as below the testing line, excepting that fluted plates were used instead of plain plates, to the underside of the stones which support the bed-plate girder. The brickwork was built with a ring of headers round the outside of each course, and the hearting was filled in with ordinary English bond, herringbone courses being occasionally introduced, and care being taken to fit the bricks as accurately as possible round the flanges of the cylinders. The bed-stones are fixed on the top of the brickwork; they are of Bramley Fall, except in two instances, where they are of granite. Each bed stone is in two pieces, and is 24 inches thick.

Weighting and Testing the Cylinders.

Each of the cylinders was weighted at the testing line with 850 tons of iron. This weight was calculated to represent the dead weight of the structure above the testing line, a rolling-load of one ton per foot forward for each line of way supported by the cylinder, and a moving-load on the footpaths. The weight was applied by packing rails, kentledge, and pig iron, on the cylinder. Careful observations were taken before and during the loading. When the whole weight was resting on the cylinder, levels were taken every other day, until it was found that no subsidence had taken place for seven days. The order to remove the load was then given, and the dimensions having been taken for the making-up, or special ring of cylinder-plates, and the ring having been cast, the erection of the cylinder was proceeded with. The greatest subsidence under the full test-load was $2\frac{5}{8}$ inches, and the least $\frac{1}{8}$ inch. The labour of testing in this way every cylinder was considerable, and delayed the progress of the works. The results, however, show the necessity of the precaution. Subsidence was almost invariably observed before the total test-load had been placed on the cylinder. The heaviest weight on the London clay at the bottom of any of the cylinders is 5·84 tons per superficial foot, with a rolling-load as stated above; and the heaviest weight on the brickwork in the cylinders is about 9 tons per superficial foot.

The Bed-plate Girders.

(Figs. 7 and 8.)

On the top of the Bramley Fall stones, which form the top of the cylinders, the bed-plate girders are fixed transversely to the axis of the bridge. Each pier has two bed-plate girders, and all of them are alike, excepting that supporting the main girders of the

Fan, which is wider and stronger than the others. The bed-plate girders are all box girders; they are 4 feet wide on the top and bottom flanges, and 2 feet 4 inches high, except the one already specially mentioned, which is 5 feet wide. On the top of these girders on the Surrey piers and Middlesex piers are laid cast-iron roller paths planed, with wrought-iron turned rollers 4 inches in diameter. On the two centre piers there are no rollers, and the girders of the bridge there rest directly on the bed-plate girders.

Cast-iron moulded caps, which conceal the bed-plate girders, are fixed on the tops of the cylinders.

The Outside Main Girders.

(Fig. 10.)

The outside main girders of the bridge are box girders, 8 feet 6 inches high, and 3 feet 7 inches wide, with a sectional area varying with the different spans. The web-plates are $\frac{3}{8}$ inch thick, increased to $\frac{1}{2}$ inch thick for a length of 10 feet at each end of the girder. The transverse distance from centre to centre of the outside girders is 63 feet 6 inches (Fig. 2).

The Intermediate Main Girders.

(Figs. 11, 12, 13, 14, 15, and 20.)

The intermediate girders are single-web girders 8 feet 6 inches high, and 2 feet 2 inches wide. They are fixed 5 feet apart from centre to centre, the space between the outside girders and the next intermediate girder being 6 feet 9 inches from centre to centre. The girders for the two side openings are independent of the other spans, but those for the three centre spans are continuous over the three openings. The sectional area of the intermediate girders varies, of course, at different points, and also with the different spans, but it would occupy too much space to give in detail the different thicknesses of the flanges, which are all calculated for 4 tons strain per square inch in compression, and 5 tons per square inch in tension. The web-plates are generally $\frac{3}{8}$ inch thick, strengthened with additional gusset-pieces and T irons at the ends.

The Flooring.

The flooring of the bridge is composed of wrought-iron flat plates, $\frac{1}{2}$ an inch thick, riveted to the top flanges of the main girders, extending from girder to girder, and strengthened with angle or T irons. On the Fan (Figs. 9 and 20), where the main girders are from 5 feet to 12 feet apart, cross girders are employed, in order to carry the roadway plates. These cross girders are about 1 foot 3 inches

deep, and are 3 feet apart from centre to centre. The floor of the bridge forms the Station Yard, and is occupied by cross roads as well as by the through lines. It was necessary, therefore, to adopt a covering for the bridge which should be able to carry the rolling load in any direction. This purpose is fulfilled by the floor of wrought-iron flat plates; while, at the same time, the strength of the bridge is much increased by them, both longitudinally and transversely. Upon the flooring plates asphalte, dressed to proper falls, is laid, and pipes are fixed to the cylinders to carry off the rain-water. At the piers, where rollers are employed, the flooring plates are not longitudinally connected, but are separated by an open space of about 10 inches; under this gap a cast-iron gutter for surface drainage is fixed, which is attached to the girders on one side only, and travels with them as they contract or expand. On the asphalte an average thickness of 5 inches of ashes is placed as ballast, and on this the ordinary permanent way is laid with cross sleepers. No special permanent way is thus required for the bridge, a point of considerable consequence in a position like this, where renewals are continually required, and where the number of points and crossings is unusually large.

The Cross Strutting.

Strutting is introduced transversely between the girders: there are three tiers of diagonal struts in each opening, and there are also tiers of horizontal struts, composed of T irons fixed between the bottom flanges. Great transverse strength is also given to the bridge by the $\frac{1}{2}$-inch wrought-iron flooring plates, which are, as has been already stated, riveted to the girders and extend completely across the bridge.

The Footways, &c.

(Fig. 2.)

To the outside box girders ornamental cast-iron cantilevers are attached to carry the footpaths, which project from the girders and overhang the river. These castings are attached to the girders by bolts, which pass through the girders from side to side, with thimbles or distance pieces between the two webs. The footways are formed of creosoted Baltic planking 4 inches thick, upon which is laid a layer of felt, and on that asphalte. There are cast-iron parapets on each side of each footpath. That next the river is pierced, and that which separates the railway portion of the bridge from the footpaths is solid. Ornamental cast-iron pilasters are fixed over each pier, and rest on the ends of the outside girders.

The Signal Bridge, &c.

(Figs. 1 and 2.)

Over the Middlesex pier the signal bridge is fixed; it is about 62 feet span, 11 feet 6 inches wide, and rests on four cast-iron pillars, connected together in pairs on each side by castings. One of the pillars on each side rests on the outside girder of the Fan span, and the other pillar rests on the girder of the adjoining span. As these girders rest on rollers, and are free to move with the expansion and contraction of the iron, rollers were also placed under one of the pillars supporting the signal bridge on each side. The girders of the signal bridge are wrought-iron lattice girders. They are firmly bolted to the pillars, and are strutted transversely: the cross girders are of wrought iron, and the floor is of creosoted Baltic planking, 4 inches thick. The cast-iron parapets and pilasters of the bridge are all provided with compensation for expansion and contraction, as also are the water and gas mains.

The Cost, &c., of the Bridge.

The piers of the bridge, from the bottom of the cylinders to the bed-plate girder, contain in all about 2,500 tons of cast and wrought iron. The superstructure contains about 4,200 tons of wrought iron in girders, floor plates, &c., and about 1,100 tons of ornamental castings in cantilevers, railings, and pillars, &c. The cost of the Cannon Street Bridge, including the abutments, signal bridge, and all things connected with the work, with the exception of the permanent way, signals and signal apparatus, gas and water mains, amounted to £193,000. This sum gives £2 15*s.* as the cost per superficial foot, and £250 per lineal foot, or £50 per lineal foot per line of way including the Fan and the footpaths.

The cost of the Charing Cross Bridge was estimated by Mr. Hayter (M. Inst. C.E.), in the Paper which was read before the Institution while the works were in progress, at about £180,000,[1] or nearly £1 15*s.* per superficial foot, and £131 per lineal foot. In this estimate, however, some items of expense, such as the signal bridge, footway approaches, and additional ornamental work to the abutments and piers, were not included; and, in order to institute a comparison between the two bridges, these must be added. If this be done, the cost of all the works at the Charing Cross Bridge, which in the parallel case of the Cannon Street Bridge are included in the above sum of £193,000, will have amounted to £202,000, or to £2 per superficial foot, and to £150 per lineal foot, or £37 10*s.* per lineal foot per line of way, including the fan and the foot-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 525.

paths. The cost per superficial and lineal foot of the Cannon Street Bridge appears, therefore, to be considerably in excess of that of the Charing Cross Bridge; but in the comparison it is to be remembered, first, that at Charing Cross the Company had the two brick piers of the Suspension Bridge, and part of one abutment already built; secondly, that the floor of Charing Cross Bridge is of timber instead of wrought iron; and, thirdly, that the weight per superficial foot on the London clay is less at the Cannon Street Bridge than at the Charing Cross Bridge. If all these circumstances be taken into account, it is believed that the comparative cost of the two bridges will not be found materially different. The great width of the Cannon Street Bridge rendered the use of cross girders unadvisable, unless a central longitudinal girder projecting above the roadway had been employed: this was clearly inadmissible, from the fact that the bridge had to be capable of carrying cross roads in all directions. The space between the necessary level of the rails, with regard to the Cannon Street Station, and the headway prescribed for the river traffic, would only admit of girders of the height above mentioned, which is about $\frac{1}{16}$th of the span, and therefore not of an economical height. This fact tended to increase the cost of the bridge, as compared with others, where the height of the girders is not limited by such considerations; but nevertheless, and with these disadvantages, the cost will, it is believed, be found to compare favourably with that of other railway bridges in similar situations.

THE CANNON STREET STATION.

(Plate 16.)

The length of ground between the River Thames and Cannon Street is 855 feet, which is occupied as follows:—the forecourt is 90 feet wide, the booking offices are 85 feet wide, and the length of the covered portion of the station south of the booking offices is 680 feet. Two of the platforms are prolonged beyond the covered portion, and extend nearly up to the signal bridge over the Middlesex pier. The width of the station outside the walls is 201 feet 8 inches, and inside the walls, at the platform level, it is 187 feet. The station stands, to a great extent, on the site of the old Steel Yard; it is almost entirely bounded, except on the river side, by public thoroughfares, and is intersected by Upper Thames Street, which crosses underneath it at about half its length.

The Substructure of the Station.

(Figs. 16, 18, 19, and 21.)

The whole of the station is built on a substructure of brick piers and arches, excepting the booking offices and the part which is over

Upper Thames Street. At the crossing of this street it was necessary, in order to give the requisite headway for the street traffic, to use wrought-iron girders, and therefore to stop the series of arches by heavy abutments. The axis of the station is not parallel to the centre line of the bridge: this want of parallelism is made up in the pier next to the river abutment, the south face of it being at right angles to the bridge and the north face at right angles to the station. The thickness of the ordinary piers is 5 feet throughout, widened by footings at the base to 8 feet. The footings rest on concrete, the bottom of which is on the gravel overlying the London clay, or on the London clay itself, at depths varying from 16 feet to 30 feet below the surface of the ground. The piers are T shaped at the ends, walls being built under the ends of the main arches to relieve the weight of the station walls and roof. Openings 12 feet wide are left in the piers, so arranged as to allow tramways to be worked throughout the basement if necessary; and provision has been made in the arches for an hydraulic lift to raise and lower the wagons. Excepting in the river abutment, the greatest thickness of the walls of the substructure is from 5 feet to 6 feet, open spaces or pockets being built in all the piers or abutments whose outside dimensions exceed 6 feet. The piers and abutments are almost entirely built with ordinary grey lime mortar. The span of the main arches is 28 feet 6 inches; they are segmental, and the rise in the centre is 9 feet: those south of Upper Thames Street are built in grey lime mortar, and those north of that street, which are groined, are almost entirely built in Portland cement. The general thickness is 1 foot $10\frac{1}{2}$ inches, or five rings of bricks, and an additional ring is built under the station-wall, extending inwards about 15 feet from the ends of the main arches. The 12-feet openings in the piers south of Upper Thames Street have semicircular arches 1 foot 6 inches thick, built in Portland cement below the springing of the main arch. The cross openings north of Upper Thames Street are mostly carried up through the springing of the large arch, and are groined into it. The section of the smaller groined arch, covering the 12-feet cross opening, is a portion of an ellipse the major axis of which is vertical. By adopting this form of arch, the groin points are kept in straight lines from the centre of the arch to the piers, which is important in brick-groining, and desirable in stone groining (Fig. 19). The groining, which is 2 feet 3 inches thick, is built in Portland cement, and the keystone is of Bramley Fall. The groining was adopted north of Thames Street in consequence of the height of the ground, which prevented communication between the different main archways being possible by transverse arches below the springing of the large arch. Without intercommunication the value of the vaults would be commercially much diminished, and they would not have been available as

they now are for parcels offices, stores, and railway purposes. The Author thinks that, in metropolitan works, the adapting to commercial uses those parts of railways which are only structurally necessary, and are not required to be occupied for railway purposes below the level of rails, should not be lost sight of; and that very often a small judicious addition to the first cost will be amply repaid by the increased yearly rental which, in consequence, will be commanded. In the present instance the increased cost of the groining was about £1,050, or £·042 per superficial foot; a small sum as compared with the increased value which it has given to the basement. A series of arches sloping upwards from Upper Thames Street towards the river at an easy gradient, and then turning the reverse way with a gradient of 1 in 12, affords access for empty cabs to the level of the platforms at the south end of the station, in order that they may thus avoid meeting the stream of traffic passing out at the north end of the station. The whole of the arches of the substructure are covered with asphalte dressed to falls, and provided with cast-iron drain-pipes. The rails and platforms are carried across Upper Thames Street on wrought-iron girders 2 feet 6 inches deep, the span being 37 feet: the girders are 4 feet 10 inches apart, and the width of the bridge is 202 feet. The floor of the bridge is of creosoted Baltic planking, 8 inches thick.

The Station Walls.

(Figs. 16, 17, and 21.)

The walls are almost entirely of brickwork in mortar—the only exceptions being the arch over Upper Thames Street, and a few courses on the top of the wall, which are laid in cement. The height of the walls is 45 feet from the level of the platforms to the top of the bed-stones of the roof trusses; or about 51 feet from the top of the arches of the substructure. The ordinary piers of the walls are 13 feet 6 inches wide, and 6 feet 4½ inches minimum thickness: the panels are 20 feet wide and 2 feet 7½ inches thick, these dimensions being exclusive of plinth and string-courses. The walls are carried over Upper Thames Street by a semicircular arch, built in Portland cement, the span of which is 37 feet. It is built with eight 4½-inch rings of brickwork, and is 7 feet 6 inches wide. The trusses of the roof rest on Bramley Fall bed-stones 6 feet 6 inches by 5 feet, by 2 feet thick.

The Roof.

(Plates 16 and 17.)

The main trusses of the roof, which is somewhat similar in character to that of the Charing Cross Station, consist of segmental ribs with a tie-bar looped up. The clear span of the trusses is

190 feet 4½ inches. The rise of the rib at the centre is 60 feet, and the rise of the tie-bar is 30 feet. The truss, therefore, is 30 feet deep at the centre. The rib is 1 foot 9 inches deep, and is made like an ordinary riveted girder. The flanges are 14 inches wide and ½ inch thick; the web is ⅜ inch thick, and the angle-irons are 3 inches by 3 inches by ½ inch. The tie-bar, which is of uniform section throughout, is cylindrical, $5\frac{5}{16}$ inches in diameter. The mode of attachment of one length of the bar to the next and to the verticals and diagonals is shown in Fig. 32. The verticals are made of two T irons bolted together back to back, with stiffening-plates to each T iron. The diagonals are plain bars 6 inches wide and ½ inch thick. The rib is widened out where it is seated on the walls; an additional web-plate is riveted to the ordinary web, and the rib is, as it were, split into two parts, a casting being placed between them (Fig. 30); by this means the area of the end of the rib, where it rests on the wall, is increased to 4 feet by 2 feet. The principals are fixed on the eastern wall by holding-down bolts (Fig. 31); but on the western wall they are seated on wrought-iron collars with a peculiar saddle or bed-plate (Fig. 29). The ordinary distance from centre to centre of the trusses is 33 feet 6 inches, being the same as the distance between the centres of the piers of the substructure. In crossing Thames Street, however, the distance apart was increased to 35 feet 1½ inch, in order to suit the abutments of the bridge over that street. The weight of a single truss is 47¼ tons. The purlins are single web-girders 1 foot 8 inches deep; their flanges are composed of two angle-irons 5 inches by 3 inches by ½ inch, with a ⅜-inch web (Fig. 34). They extend from rib to rib, and rest between the flanges of the rib, to which they are attached by bolts, with holes slotted to provide for expansion and contraction. Light lattice strutting is fixed half way between the trusses, in order to prevent any sagging of the purlins. The sash-bars are of T iron, 3 inches by 3 inches by $\frac{7}{16}$ inch; and the glass used is rough plate about ¼ inch thick. The parts of the roof not glazed are covered partly with zinc and partly with slating. The zinc is laid with rolls on each side of the central lantern where the slope of the roof is flat, and where it is necessary for workmen employed in repairs to walk; and again on a narrow width below the glazed portion, where a light wrought-iron and wood balcony is fixed from end to end of the roof for the use of men employed in repairs or painting. A lantern, 22 feet wide, extending nearly the whole length of the roof, is glazed on the top, and has the sides fitted with louvres, which afford means of ventilation. The gutters are of cast iron, connected together in lengths of about 67 feet, with a space between the different lengths to provide for expansion and contraction. Each length of gutter has two pipes 6 inches in diameter to carry off the rain.

The Gable Screen.

(Plate 16, Fig. 16.)

At the southern end of the roof, and resting on the two towers, is the gable screen. It consists of two wrought-iron trusses, segmental at the top, of the same radius as that of the ribs of the roof, and nearly horizontal at the bottom, the trusses being 59 feet deep in the centre. These two trusses are 11 feet apart from centre to centre, and they are connected together at numerous points, so as to form one large girder. A camber of 12 inches was given to the bottom of the trusses, in order to avoid the appearance of sagging, which is so noticeable in long horizontal lines. The glass is carried in the gable-screen in wooden frames made to fit between the iron struts and ties.

The Staging for the Roof.

The timber staging for erecting the roof was movable. It extended from wall to wall of the station, being 180 feet wide and 58 feet long in the direction of the length of the station. It contained about two hundred and fifty loads of timber, and was supported at seven points by wheels running on rails and sleepers, there being five wheels at each point. The wheels were 32 inches in diameter, and there would probably be, when the stage was being moved, about 7 tons on each wheel, assuming that the load was equally distributed. Two stages were used in erecting the roof, both of which were movable; the larger one, which is described above, was as high as the top of the segmental ribs, and was used for erecting the trusses: the smaller stage, being low enough to pass under the tie-bar, was used for painting, glazing, and finishing. These stagings were designed by Mr. Phillips (Assoc. Inst. C.E.), and answered their purpose admirably. The trussing of the larger stage did not commence for 23 feet above the rails; by this means a certain amount of play, or absence of rigidity, was given to it, and the tendency which so large a staging would have, if bound together too firmly, to get jammed against the rails transversely, was counteracted. When the stage had to be moved, ropes and blocks were attached to the wheel carriages, and these were hauled in either all together or singly, as the foreman in charge directed. In addition to the two movable stages, fixed scaffolding was used for erecting the gable-screen.

The Cost of the Roof.

The cost of the roof of the Cannon Street Station amounted to £49 10*s.* per square of 100 superficial feet of area covered, measured

between the walls. The cost of the roof of the Charing Cross Station was £40 per square (Plate XVII., Figs. 35 to 42). At the time the contract was taken for these roofs, iron was exceptionally high, the contract price for the roofs fixed in place being £24 5s. In the above prices per square, all items of expense are included, and the adoption of this course, which is the only fair way of arriving at the cost of a completed roof, makes the price per square appear high, when compared with the prices given for other roofs, where the same mode of calculation is not followed. For instance, in the cost above given, of the two roofs under consideration, the prices of the gable principals and gable screens, the outside galleries, the repairing ladders, the expansion gear, the gutters and rain-water pipes, the roofs of the towers, and all the extra or day-work, are included. If these items of expense, which are all necessary adjuncts of a large roof, had not been included, the prices would have been reduced about £6 per square. Moreover, it is to be borne in mind, in comparing these with other roofs, that all the materials are here of a most durable character, and that all the sash-bars are of T iron; this latter item alone adding about £4 per square to the cost of the roof.

The Arrangement of the Station.

(Fig. 17.)

The Cannon Street Station has the booking-offices, waiting-rooms, and refreshment-rooms, &c., at the north end; the building containing them being at right angles to the lines of way. This arrangement, in the Author's opinion, is preferable, both for the public and for the railway officials, where there are a large number of platforms; although, perhaps, the convenience of one or possibly two platforms may be better consulted by having the booking-offices at the side of the station. In the present instance, moreover, the position of the streets would have rendered any other plan objectionable. The booking and other offices are chiefly situate on the ground-floor of the building which, above and below them, forms the City Terminus Hotel.[1] Parcels offices, stores, and cellarage, &c., are provided in the basement of the station between Upper Thames Street and the basement of the hotel. Access from the rail-level to these basement offices, the floors of which are level with the adjoining streets, is given by stairs leading from the platform at the southern end of the station; and hydraulic lifts are provided for raising and lowering the parcel-trollies. These lifts are worked by direct pressure from tanks in the towers at the southern end

[1] The Hotel was erected by an independent Company, from the designs and under the superintendence of Mr. Edward M. Barry, A.R.A.

of the station. The water, after having been used in the lifts, is discharged into tanks about 9 feet above the platform-level, and is again utilized for the water-closets and urinals, for washing carriages, and for general station purposes.

The Platforms, &c.

There are nine lines of way in the station, of which eight lines are alongside platforms, one line being set apart for spare stock and standing room. The eastern platform is 522 feet long and 13 feet 6 inches wide at the centre. The general departure platform is 665 feet long and 19 feet wide; the general arrival platforms are 721 feet long, and are 12 feet 6 inches wide opposite the cab road, and about 30 feet wide, on the average, beyond the cab road. The western platform is 486 feet long, and 13 feet 6 inches wide.

The nature and extent of the traffic required provision for a large number of trains being at the station at one time; some of them carrying mails, and many a large quantity of passengers' luggage and parcels; the duration of their stay in the station being consequently very dissimilar.

In this respect the traffic differs very much from that of the Metropolitan and the Blackwall Railways. Looking to these circumstances, Mr. Hawkshaw determined to adopt the principle of having a line of railway on each side of the platform, instead of a platform on each side of a line. It is believed that this arrangement is the most economical in space, and, relatively to the space occupied, the most convenient in working. The side platforms, from which the heavy Greenwich, Mid-Kent, and Charing Cross, and part of the North Kent traffic is worked, are each 13 feet 6 inches wide. These two platforms accommodate satisfactorily the four lines of rails on which the above traffic is carried; and it would not, the Author thinks, be possible to utilize the space so thoroughly by arranging the platforms on the opposite principle. Although, when a train arrives which has to leave again as soon as an engine can be attached, the passengers entering the train have to mix on the platform with those leaving it, yet it seldom or never happens that trains arrive at or depart from both sides of the same platform at one time; and the advantage, where the area of the station is limited, of throwing all the space available for platforms into two instead of into four platforms, more than compensates for the disadvantage of the passengers having to pass each other. The area of the platforms which are alongside trains is 43,877 superficial feet, and the length of the trains accommodated is 4,778 lineal feet, giving about 9 superficial feet of the platform for each lineal foot of train.

The Station-yard and Signals.

The station-yard may be said to extend from the end of the platforms near the signal-bridge to the southern abutment of the bridge over the River Thames, being about 600 feet in length. The five lines of way on the bridge are appropriated as follows:—

That on the western side is exclusively for trains proceeding from Cannon Street to Charing Cross; the next line is for trains approaching Cannon Street, and is used in common by trains from London Bridge or the country, and by trains from Charing Cross; the centre line is exclusively for trains arriving from London Bridge or the country; the fourth line is the main down-line, and is used by trains going either to London Bridge or Charing Cross. The line on the eastern side is used for engines entering or leaving the engine depôt, and for engines waiting for their trains. The shortness of the station-yard, confined as it is between the ends of the platform and the sharp curves on the Surrey side, added considerably to the difficulty of laying out the lines. The principle adopted is that every line should approach every platform without back shunting, excepting only that platform on the western side, which is to a great extent devoted to the short traffic to and from Charing Cross. This principle has been carried out by means of about forty pairs of points, and it is probably the only arrangement which, as the trains are all reversed here, would have allowed the traffic to be satisfactorily worked. The signals are on Messrs. Saxby and Farmer's patent, and were erected by them under the supervision of the Engineer. The signal-box and the bridge is 42 feet long by 9 feet wide; there are four posts, with twenty-four semaphore arms, eight arms being for out trains, and sixteen for in trains. The signal-box contains sixty-seven levers, of which thirty-seven work signals, and thirty work points; several of the point-levers working the switches at both ends cross over roads. The signals lock the points and each other, so that no contradictory signals can be given, nor can the permission for ingress to or egress from any platform be given until the points are arranged in accordance with the signal for that particular platform. The difficulty of arranging this apparatus so as to provide for safety without impeding the working of the station was considerable, as may be gathered from the fact that there are in the locking-frame thirty-two slides and about one thousand locks. An idea may be formed of the duty which falls on this apparatus from the fact, that seven hundred and seventy-five trains have passed under the signal-bridge in a single working day (Whit-Monday), and that each train being reversed here, a fresh engine has to be attached, the engine which brought the train in having to be passed into a siding. The Author requested that the trains might be counted and timed for

half an hour one morning, and it was found that thirty-five trains were signalled and passed in or out of the station in thirty-five minutes. Mr. Walker's electric telegraph apparatus, which works a miniature semaphore distance-signal in each box, is used for signalling the trains on the block-system between the different signalling stations. Two men are employed in the Cannon Street signal-box to work the levers, and a clerk for the telegraph instrument; they work eight hours a day.

The Cost of the Station.

The cost of the works of the Cannon Street Station is given in the following Table, the cost of the Charing Cross Station (Fig. 22) being given in parallel columns for the purpose of comparison:—

	Cannon Street Station, Area 152,632 Superficial Feet, exclusive of Fore-court.		Charing Cross Station, Area 103,672 Superficial Feet, exclusive of Fore-court.	
	Gross Cost. £.	Cost per Superficial Foot.	Gross Cost. £.	Cost per Superficial Foot.
Substructure to formation level, excluding only the north abutment of the bridge over the River Thames	74,962	·491 say 9*s.* 10*d.*	41,422	·400 say 8*s.*
Superstructure, including fore-court, booking-offices, fittings, towers, roof, gas and water mains, &c. &c.; excluding only the permanent way	157,262	1·029 say 20*s.* 7*d.*	111,604	1·077 say 21*s.* 6*d.*
Total . . .	232,224	1·520 say 30*s.* 5*d.* about 2·92 pence per cubic foot.	153,026	1·477 say 29*s.* 6*d.* about 3·37 pence per cubic foot.

The additional cost per superficial foot of the Cannon Street Station substructure is accounted for by the expense of crossing over Upper Thames Street.

The Metropolitan District Railway passes in a tunnel underneath the forecourt at Cannon Street, at a depth of about 28 feet below the surface. In order to avoid inconvenience, this short length of tunnel was built simultaneously with the works of the station, and was completed prior to the opening of the City Terminus Extension Railway.

THE VIADUCTS, ETC., SOUTH OF THE THAMES.

Of the five lines of way on the bridge over the River Thames, one, the eastern, turns off at the south abutment to the engine depôt, and the remaining four lines are carried on a viaduct 48 feet wide, and about 43 feet above the foundations as far as Stoney Street signals, where a junction is formed between the three lines bending eastward to London Bridge, and three lines bending westward to Charing Cross. The viaducts are of brickwork, except where the Borough Market, York Street, and Park Street are crossed. The ordinary spans of the brickwork arches are 25 feet and 30 feet; the minimum thickness of the piers is 4 feet, and the thickness of the arches generally is 1 foot 10½ inches. Park Street is crossed by means of wrought-iron girders 32 feet span and 3 feet 3 inches deep, covered with 7-inch creosoted planking. The Borough Market and York Street are crossed on a viaduct of five spans, consisting of wrought-iron girders from 40 feet to 50 feet average span, and 4 feet deep, resting on cast-iron hollow columns 2 feet in diameter. The columns are 24 feet high, and rest on foundations of brickwork and stone landings. The cost of the whole of the viaducts south of the River Thames, exclusive of the permanent way, was £32,000. The cost of the Borough Market and York Street viaduct, including abutments, was £8,775, or about £107 per yard forward for a treble line. The cost of the ordinary brickwork viaduct for three lines, 38 feet wide, and about 37 feet high from the foundations, was £39 per yard forward; and the cost of all the viaducts, including the Borough Market and girder-bridges, was at the rate of £66 per yard of treble line.

The Engine Depôt.

An engine house, engine turn-table, water-tank, and coking-stages, &c., are provided on the south side of the river. The ground which was appropriated for the depôt was of an awkward shape, and confined by the streets adjacent. In consequence, engines are obliged to go on to the turn-table in order to get in or out of the engine shed. The depôt is carried on a basement of brick piers and arches, and the cost of the whole of the depôt works, exclusive of permanent way and the turn-table, was £26,000.

The Permanent Way.

The permanent way consists of wrought-iron rails, weighing 75 lbs. to the yard, in cast-iron chairs weighing 34 lbs. each. The sleepers are of rectangular Baltic timber, creosoted, 9 feet long by

10 inches by 5 inches. Eight sleepers are laid to a 20-foot rail, excepting in the station, where seven only are used. Check-rails are laid round the curves on the south side of the river, which are about 8 chains radius, the check-rail being raised ½ inch above the running rail. The switches and crossings are of steel throughout. The traffic on the railway imposes a severe duty on the permanent way. Taking the gross traffic, and assuming it to be equally distributed over four lines of way, it is found that about 6½ millions of tons per annum pass over each line of way, of which weight about one-third consists of locomotives. The grinding action of the wheels on the curves increases the wear and tear, so that wrought-iron rails cannot be expected to last very long. Looking to the heavy traffic expected, and the difficulty of repairing the road during working hours, Mr. Hawkshaw wished to lay steel rails; the Directors, however, were doubtful of the expediency of so doing, and did not adopt his recommendation.

The Total Cost.

The total cost of the works of the City Terminus Extension Railway was £505,336, and the cost of the works of the whole Charing Cross Railway, including the City Terminus Extension, has been £1,160,118. The cost of the land for the whole railway, after deducting the value of surplus land, Hungerford Bridge, and pier tolls, &c., &c., was £1,900,000, making a total for land and works slightly in excess of three millions. In this sum, it is to be remembered, are included about 4½ miles of railway for double line, two large bridges over the River Thames, a considerable number of expensive street bridges of large spans, and two of the largest Metropolitan Termini. The cost to the South Eastern Railway Company of the Charing Cross Railway is no doubt a heavy burden; but, on the other hand, it must be conceded that the Company have not spent the money on any useless or valueless project. The works are all of a most durable character; the freehold property belonging to the Company under the arches of the two stations and of the viaduct, is alone of great value; the two stations yield to none in point of situation, and the value of the traffic, which at present is not fully developed, is proved by the fact that at the present time about fifteen millions of passengers are annually carried on the railway.

Conclusion.

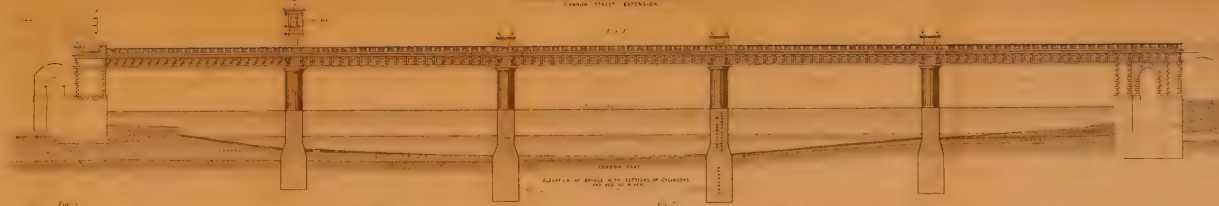
The Author feels, in submitting this Paper to the Institution, and in bespeaking the forbearance of the members for its defects, that he is bringing before them a subject which involves no new

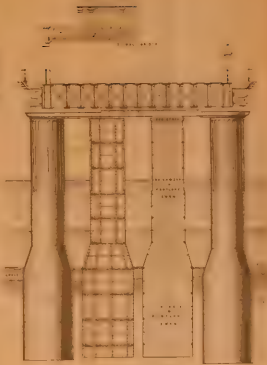
principles of theory or practice. He trusts, however, that the description and statistics of a work with which most of those present are more or less, as members of the public, acquainted, will not be devoid of interest, and may possibly give rise to a discussion which may redeem any shortcomings on his part.

The Paper is illustrated by a series of diagrams, from which Plates 15, 16, and 17, have been compiled.[1]

[1] The Author has added to the plates which illustrate this Paper a plan of the Charing Cross Station (Fig. 22) and the details of the Charing Cross Station Roof (Figs. 31 to 42), in order that this Paper, when taken in conjunction with that by Mr. Hayter* (M. Inst. C.E.), may form a complete record of the whole of the Charing Cross Railway.

* *Vide* Minutes of Proceedings, Inst. C.E., vol. xxii., p. 525.

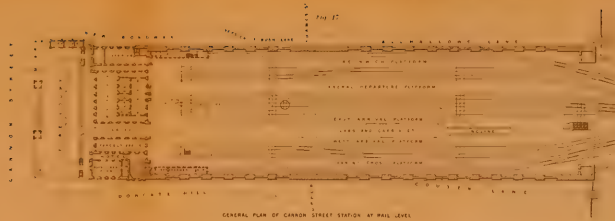




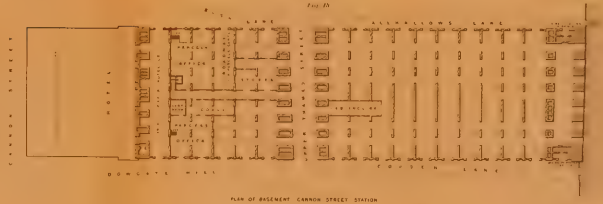
CHARING CROSS RAILWAY.

CANNON STREET EXTENSION.

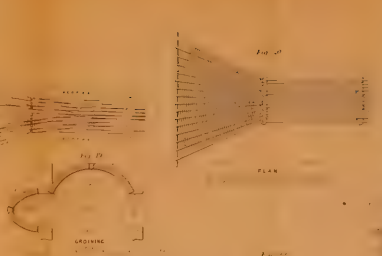
HALF ELEVATION AND HALF SECTION CANNON STREET STATION

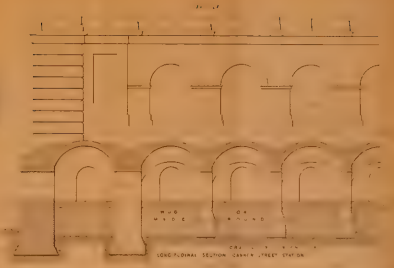


GENERAL PLAN OF CANNON STREET STATION AT RAIL LEVEL

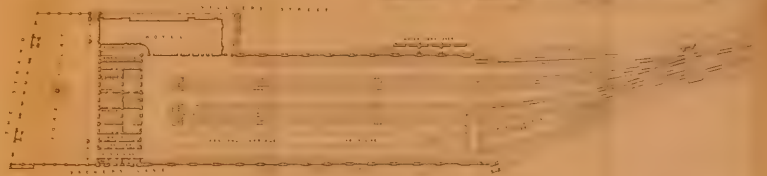


PLAN OF BASEMENT CANNON STREET STATION





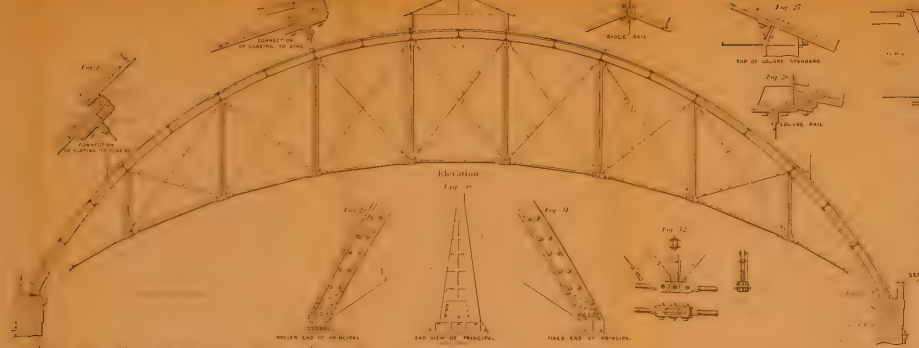
LONGITUDINAL SECTION CANNON STREET STATION

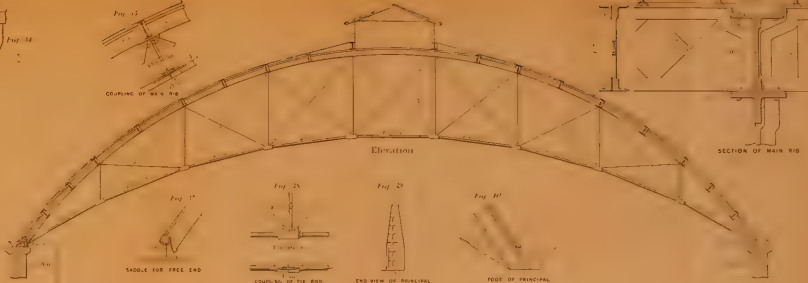


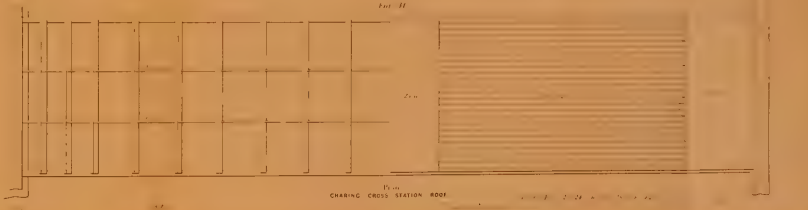
GENERAL PLAN OF CHARING CROSS STATION AT RAIL LEVEL

CHARING CROSS RAILWAY.

CANNON STREET EXTENSION







Mr. J. W. Barry said, that in the Paper he had given the cost of the land of the Charing Cross Railway, including the City Terminus Extension, at £1,900,000, and the cost of the works at £1,200,000, making together £3,100,000. The price of the land was arrived at by Mr. Ryde, the Surveyor to the Company, after deducting the sums paid by the Company for the tolls of the Hungerford Bridge and of the Hungerford steamboat pier, which together amounted to £140,000, as well as the price of the shares held by the South Eastern Railway Company in the City Terminus and the Charing Cross Hotels, which together amounted to a further sum of £130,000, and after also taking credit for the surplus lands. He was anxious not to be understood as having given the total capital cost at which the Charing Cross Railway stood in the South Eastern Railway Company's books; because there were other miscellaneous items of expense, such as the loss of interest during construction, rates and taxes during construction, and legal and parliamentary expenses, amounting in all to about £600,000, which would have to be added if the real cost was to be given. Adding the value of the surplus lands, the price of the tolls, the price of the shares in the two hotels, and the miscellaneous expenses, the total capital cost of the Charing Cross Railway, including the City Terminus Hotel, amounted to £4,070,000. It was, however, fair to remark, that the tolls were still in existence, and produced a revenue; that the Charing Cross Hotel paid a dividend of from 10 to 12 per cent.; and that the surplus land was of value distinct from railway purposes. The freehold land possessed by the Company under the arches of the railway was also of great value, totally irrespective of the traffic, and was scarcely as yet developed. Mr. Ryde believed that the letting value of the land under the arches, capitalised at twenty years' purchase, would go a long way towards paying the cost of the viaduct, excluding, of course, the bridges over the roads; and the rent of the vaults under the station would, if similarly capitalised at twenty years' purchase, probably pay the cost of the station up to the formation level.

Mr. W. H. Barlow said as an idea prevailed in some quarters, that the roof of the Midland Railway station at St. Pancras, had been more costly than other roofs of large span, he would take this opportunity of placing on record a few particulars with regard to that structure; and alongside the figures so given he would add, for the purpose of comparison, similar details as to the roof of the Cannon Street station. Owing to the roof of the St. Pancras station springing from the ground level, instead of from the top of the walls, the weight of the roof was not borne on the walls, and, therefore, the walls were made thinner.

COMPARATIVE STATEMENT.

	St. Pancras Station.	Cannon St. Station.
	ft. in.	ft. in.
Height of the walls above the rail-level	40 0	48 6
Average thickness of the walls above the rail-level	3 6	5 0
Span of the roof	240 0	188 6
Weight of principal, including spandril frame and wrought-iron foot, to the level of the floor-girders	52 tons.	
Weight of truss, commencing at the top of the walls	..	47 tons.
Distance from centre to centre of principals	29 ft. 4 in.	34 ft.
Area supported by one principal, measured on plan	7,040 sq. ft.	6,426 sq. ft.
Cost of each principal	£962	£1,128
Height from the rail-level to the upper side of principal	105 ft.	108 ft. 6 in.

The reason why in one case 50 tons were procured for the same cost as 40 tons in the other was, that, in the cheaper structure, the whole of the work was of common riveted bridge-iron, and did not involve screw cutting and boring. He had not given the price per square, because that included the cost of covering, which differed in the two cases. One part of Cannon Street station was covered with Muntz's metal, and the other part with glass. In the St. Pancras station there was a tie below the level of the rails, altogether irrespective of the roof, and in that way great depth had been obtained for, what he might call, the roof girder. That was an advantage which did not obtain when the roof sprang from the top of the walls. He had not included the weight of the tie, as it formed no part of the roof. When the station was decided upon, its level, being governed by circumstances over which there was no control, turned out to be 16 feet above the level of the road. The Directors and the General Manager then determined, that this space should be utilised for special purposes, and accordingly the substructure was composed of columns and girders. The result was a ready-made tie, and this was taken advantage of in designing the roof. He believed this was the first large roof of that construction.

Mr. J. T. HARRISON stated that the design he sent in for the building for the Exhibition of 1851 was similar in principle.

Mr. HAWKSHAW,—Past President,—remarked, that a roof was now standing in Bradford, which he constructed nearly twenty years ago, springing from the platform level; and he thought one had been erected on the Preston and Wyre Railway before that.

With regard to the cost of roofs, comparisons could not be usefully made, unless every particular was included. For instance, it appeared that in the roof of the St. Pancras station wooden sash-bars were to be used; whereas in the Cannon Street station roof the sash-bars were all of iron. No doubt in that way a large roof would be obtained at a moderate cost for its size, and he thought it would be a fine work. Again, the tie-bars across the whole width of the St. Pancras station served another and useful purpose.

In respect to the cost of the Charing Cross Railway, the Author had done what engineers were liable to do; he had denuded the capital account of several extraneous items. The cost of the work was known exactly; it was under £1,200,000; and Mr. Ryde, the surveyor, by deducting the items that had been mentioned, had cut down the cost of property, which, from his point of view, might be right. Still, having to deal with what stood in the books of the company, Mr. Hawkshaw did not think it would be proper to let it go forth that the Charing Cross Railway, including the Cannon Street extension, had been made for £3,000,000. It, in fact, in round numbers had cost £4,000,000. That sum, no doubt, provided for the items mentioned, and a good deal of surplus land; indeed on some portions of the line there was room for three, and in others for four lines of way. He would not pretend to value that surplus land; but he thought it right to state that the whole of the property, including the spare land, the pier and bridge tolls, &c., cost about £4,000,000. That exceeded the Parliamentary estimate, but that estimate was for a work of less magnitude; in the first place, it was for two lines of way, while three had been laid, and four provided for. The Charing Cross Bridge had been widened from two to four lines, and the Cannon Street Bridge from two to five lines of way, and the stations were twice as large as originally intended.

Mr. Hood said the question was whether, in the cases both of the Cannon Street and of the St. Pancras roofs, an unnecessary outlay was not incurred to secure the advantage of one large span over the entire area. What was wanted in a station roof was good ventilation, plenty of light, and freedom from obstruction. He thought that a good roof could practically be constructed in stations of this character, which would secure the great points of simplicity, durability, and freedom from obstruction, at a much more moderate cost. He had seen nothing which led him to doubt, that the principle he had adopted in the construction of the Brighton Company's Victoria station was the correct one. There, a breadth of 240 feet was divided into two spans of 120 feet each, and the columns were put in the cab road, out of the way of danger from the chance of a train running off the line. The roof of that station was carried by transverse trussed girders, each 120 feet span, and placed 50 feet apart, so that the cross girders were each 50 feet span. The framing was entirely of iron, covered with boarding, 1½ inch in thickness and iron-tongued, and slated, the slates being laid with a 4-inch lap; and iron sash-bars were used throughout. By adopting the principle of trussed girders, it did not matter where the columns were placed, because the girders could always be made uniform in appearance across the lines of railway, every part of such a structure was accessible, and could be renewed at pleasure, without interfering with any other part.

Moreover, such a station could be enlarged without pulling anything down, by additions to the sides, and the columns could be moved by strengthening the girders. The roof of the Victoria station, where there was no thrust upon the walls, which were very light, had cost, over an area exceeding 3 acres, £17 per square of 100 feet measured on plan, as compared with nearly £50 for the roof of the Cannon Street station. To that £17 per square must be added about two guineas per lineal foot, for the longitudinal columns and girders, which would bring the total average cost to something under £20 per square of 100 feet. Although the lowest tender was accepted, everything was of the best description; the workmanship and materials were excellent, and the cost was increased by a certain amount of ornament in the details. He did not see how, with large spans, such as those at Cannon Street or at Charing Cross, the station could be widened without affecting the whole of the existing structures. He thought the Cannon Street station-roof might have been constructed at half the stated cost, if it had been divided into two spaces, and if the columns had been placed in the cab road, or on one of the platforms. He believed the arched roof belonging to the London, Chatham, and Dover Railway Company at the Victoria station cost a little more than that of the Brighton Company's station; although it must be borne in mind, that it was covered with zinc, that the rafters were of wood, and that it was nothing like so durable as a roof covered with boarding and slating.

Mr. J. A. Longridge thought the Author of the Paper was quite right in giving the cost as an engineering work, although Mr. Hawkshaw might also be right in wishing to explain that £3,000,000 did not represent the real cost to the Company. The line had cost £3,000,000; with the other £1,000,000 engineers had nothing at all to do.

Mr. R. P. Brereton remarked, that the question of the size of roofs for stations had become one of grandeur and magnificence of appearance; but there was no actual necessity for the large spans which had recently come into fashion. Paddington station, which was some sixteen years old, was one of the first in which large and lofty spans of iron roofs without any ties had been introduced. There the centre span was 102 feet, and there were two side roofs with spans of about 70 feet each; and no inconvenience resulted from the supporting columns in the middle of the intermediate platforms. The Great Northern station at King's Cross had one of these roofs without a tie. It was found substantial so long as there was something more than a bare side wall to spring from; and in the case of the St. Pancras station there was, fortunately, not only a side wall, but about 20 feet of solid brick wall opposite to each rib, and he believed these

were what would have to be principally relied upon for support. The ties would probably not be required for any great service, and if they should ever become hot, they might rather assist in pushing out the roof. It was desirable that shareholders should not suppose that these grand and magnificent structures were altogether hopeless outlays. According to the Paper, about one-half of the passengers using the stations under discussion were local passengers, and the receipts from them would amount to about 2½ per cent. upon the outlay. If that were so, after the first year there need not be complaints of extravagance and of money being thrown away. About thirteen thousand local passengers used those lines daily, and at four pence each, which was an average fare, this would yield 2½ per cent. on the outlay.

Mr. HEMANS thought it would be desirable to put on record the comparative cost per square of the roofs of the stations at Cannon Street, Charing Cross, St. Pancras, Victoria, Lime Street, Liverpool,[1] and New Street, Birmingham.[2]

Mr. J. H. PORTER thought that the Birmingham station roof had cost about £30 per square. He entirely agreed that roofs of such enormous span were unnecessary, as the cost was evidently much greater as compared with that of roofs of less span. For all purposes of accommodation, and for the avoidance of all possible risks, he thought 120 feet spans ample; and it should be considered that the weight of the principals must be taken as very nearly the squares of their spans. He had built a roof for a structure in St. Petersburg of 140 feet span, the principals of which were at intervals of 14 feet, and weighed 9 tons each. This roof was designed abroad, and he compared its weight with the weights of other structures, and amongst others the Birmingham station roof, of which the weight of the principal of 212 feet span was about 24 tons. Taking the weight of the 120 feet span at one-fourth that of the 240 feet span, it was obvious that such great spans were extravagant. A similar covering would require deeper longitudinal framing for those very great spans, which, of course, was all in favour of the lesser span.

The large roofs that had been spoken of were: First, that of the City Terminus extension of the Charing Cross Railway, in which the principals were of 190 feet clear span, and spaced at intervals of 33½ feet. Secondly, that of the Birmingham station, in which the principals were of 212 feet span, placed at distances of 24 feet from centre to centre. And, thirdly, that of the St. Pancras station of

[1] For a "Description of the Iron Roof over the Railway Station, Lime Street, Liverpool," by R. Turner, *vide* Minutes of Proceedings Inst. C.E., vol ix. p. 204.

[2] For a "Description of the Iron Roof, in one Span, over the Joint Railway Station, New Street, Birmingham," by J. Phillips, *vide* Ibid., vol. xiv. p. 251.

the Midland Railway, where the arches or ribs (not trusses) were of 240 feet span, the distance from centre to centre of the principals being 29 feet 4 inches, or say, 30 feet. As the two first-named were similar in the character of the trussing, and not very different in span, he proposed to compare the weights of their principals, and to apply the mean of those weights to a comparison with the St. Pancras roof. For this purpose they must be reduced to a common spacing and a common span. Let the spacing be that of the St. Pancras roof, or 30 feet; and let the span be one-half that of the St. Pancras roof, or 120 feet. In the first place $\frac{1}{11}$th must be deducted from the 33½ feet of the Cannon Street principal, and $\frac{1}{4}$th added to the 24 feet of the Birmingham principal. In like manner a similar deduction must be made from the 47¼ tons of the one, and an addition made to the 25 tons of the other. The result would be 42·59 tons in the one case, and 31·25 tons in the other; and it would be noticed that the lighter weight was for the larger span, and *vice versâ*. To reduce them to a common span of 120 feet—

Cannon Street	$190^2 : 42{\cdot}59 :: 120^2 :$	17 tons.
Birmingham .	$212^2 : 31{\cdot}25 :: 120^2 :$	10 tons.

The mean of these was thus 13½ tons; and that accorded very nearly with what he had found, from his own calculations and practice, to be due to a principal of that span, if spaced at 30 feet, but he would prefer principals spaced at 15 feet, and of course weighing one-half, or 6¾ tons. Spaced at 15 feet there would be greater stiffness in the structure generally, with great reduction in the scantling and weight of the longitudinal framing connecting the principals. The weight of the rib or arch of the St. Pancras roof was 50 tons for the span of 240 feet. Now if two spans of 120 feet had been adopted, it would have been necessary to provide one column and one girder for each bay of 30 feet, as intermediate supports, the weights of which he estimated as follows:—

A column 30 feet high would weigh, say	3½ tons.
A lattice girder 5 feet deep, of suitable stiffness, and adapted to carry the weight of 15-feet bays	3 „
Four principals, at 6¾ tons	27 „
	33½ „

so that in every bay of 30 feet there would have been a saving in weight of 16¼ tons, while the saving in the weight of the longitudinal framing would have been in nearly the same proportion. Although the arches of the St. Pancras roof were continued down to the ground, there was abundance of brickwork for the support of the roofs of 120 feet span, at a height of 30 feet.

Of course this argument applied with greater effect to roofs beyond 200 feet than to those within that span; and while he

considered spans of 120 feet ample for all purposes of accommodation, he recognised, for example, that it might be more desirable to construct one span of 150 feet than two spans of 75 feet.

Mr. J. W. Grover remarked that the price of the Birmingham roof was £16 per square, and that the span varied from 191 feet to 212 feet. Every principal was different throughout, which in ordinary cases would have increased the cost; but, by a carefully-constructed table, each part was varied proportionately in such a manner as to cause very little trouble.

With regard to the weight to be put upon roofs, he had known instances where engineers had required a maximum of 80 lbs. to the square foot, which approached the requirements of a bridge, and 60 lbs. was common enough. He thought generally principals and covering gave a weight of about 20 lbs. to the superficial foot. The effect of wind was often much exaggerated; for if it produced a steady uniform pressure of anything like 30 lbs. or 40 lbs. to the square foot, as registered at particular spots by anemometers, the Crystal Palace ought to have been blown down long ago. The roof over the North Court of the Science and Art Department, at Kensington, covered 112 feet, both ways, without intermediate supports; four 112-feet girders intersecting each other were used. It was a complicated roof, being constructed to meet certain architectural features, without any ties at all, and that ran up the cost very materially. It was covered with Hartley's thick glass, a valuable covering, but one which weighed a great deal, and was costly: that roof had cost about £40 a square, and weighed 22 lbs. per superficial foot. He had found that the French engineers had gone carefully into the question of weight in connection with the first French Exhibition, and they allowed as little as 22 lbs. per square foot for the arched roof measured on the surface, with wind and snow combined. No tie-rods were used, because, as in the St. Pancras roof, the ribs practically abutted on the ground at both ends. It was well, however, to remember, that the French engineers seldom exposed the sections to high strains. In the building in question a maximum compressive strain of $2\frac{3}{4}$ tons per square inch seemed to have been adopted for the wrought-iron members. He believed that in the Birmingham station-roof the principals cost about the same as the covering, £8 a square being put down for the principals, and £8 for the covering. He had been told that the roof of the station at Worcester, where the spans were 80 feet, only cost about £12 a square; and there had been many roofs constructed of 60 feet span, which he believed was the cheapest form, for £10 or £12 a square.

Mr. Hood said that, when constructing the Victoria Station roof, he had been informed by the Engineer of the Great Western Rail-

way, that the cost of the Paddington roof was £19 a square, exclusive of columns and girders.

Mr. E. Ryde stated that the actual money paid for land for the Charing Cross main line and station was about £1,362,000; that was to say, a sum of £560,000 was paid for land in Middlesex, and £802,000 for land in Surrey; but the former amount included the purchase money of the Charing Cross foot-bridge, which the Company were compelled to buy, although they did not want it. The bridge, which was earning upwards of £4,000 a year, was acquired at twenty years' purchase. During the construction of the station the tolls were not continued the same; but in future the bridge would probably earn 5 per cent. upon its cost. That, therefore, was a distinct property, and the two properties should not be confused with each other. It was a question whether railways in London would or would not pay, and to ascertain this, that which belonged to the railway must be separated from that which did not. The same observation applied to the Charing Cross pier dues, which were still received by the Company, except in so far as the Metropolitan Board of Works had interfered with them, and in that instance the Board had paid compensation. The £65,000 put down for shares in the Charing Cross Hotel, which shares Lord Redesdale compelled the Company to hold, represented an expenditure for land which would not have been required for the railway, including that occupied exclusively by the Hotel Company in Villiers Street. All these separate items of expenditure being deducted, left the cost of the land for the Charing Cross line proper and the Charing Cross station at £1,000,000, including land for a fourth line of way, and for a station at Waterloo, which the Company were shortly going to build. On the question of St. Thomas's Hospital, he only took credit for £150,000, which was the sum in cash for which the Company sold the surplus land; but they had a second mortgage on that property for an additional sum of £20,000. In regard to Cannon Street, the cost had been correctly stated.

One feature of railways in London was the comparative advantage and cost of underground and overground railways. He could demonstrate that railways above ground were the cheapest, provided the arches were built so that they might be advantageously let; and the Author was quite right in saying, that the arches would pay 5 per cent. on the cost of construction, assuming the cost of railway arches to have been correctly stated. The arches under Cannon Street station would not, in his judgment, realise the rents that had been anticipated, but they would realise sufficient to pay interest on the cost of construction, as those along the line of railway had done already; that was a result which could not be obtained from underground railways.

Mr. J. W. Bazalgette thought that the statement that the

arches of railways would pay 5 per cent. upon the outlay was too general and somewhat doubtful. This statement, he believed, could have reference to a few exceptional cases only, for he had found that the bulk of the arches carrying overground Metropolitan railways were not occupied: therefore the argument in favour of Metropolitan overground railways as against underground railways, based upon such an assumption, was hardly satisfactory. Perhaps that opinion could be supported by a more definite statement of the facts, which would tend to justify such a conclusion. The comparison of the advantages and cost of the overground and underground railways within the Metropolis was so important a subject, that such information would have a prominent bearing in the designing of future Metropolitan railways; and certainly without a large return, in the shape of rent, for the arches, to meet the cost of the purchase of property required for overground railways, it would be found that in London those constructed underground were much less costly than those constructed on arches, although the works involved in the former were frequently of a difficult and costly character.

Mr. T. E. Harrison, Vice-President, thought that in comparing a large span with two small ones, the cost of the columns and the cross-girders ought to be included. In the North of England, where Directors looked not a little to the pounds, shillings, and pence, if it were proposed to make a span of 240 feet the inquiry would at once be made, Was there a necessity for that, and what would be the cost as compared with two spans or even three spans? He had been governed entirely by considerations of cost in the cases in which he had introduced smaller spans: and he knew from experience that roofs varying in span, from 80 feet up to 120 feet, with the columns, cost from £13 to £20 a square as a maximum. He had never found any difficulty in arranging a station with a divided roof. Where Directors looked upon the question of cost as an important element, he, as their Engineer, had been so governed in making his designs.

Mr. Phipps observed that the area of foundation-bearing surface was so much greater in the Cannon Street Bridge than in the Charing Cross Bridge, as to give a pressure of 6 tons on the square foot only in the former case, while in the latter it came up to 8 tons.

Mr. Hawkshaw, Past President, said the difference of construction rendered more columns necessary in the Cannon Street Bridge, as the longitudinal girders required to be supported across the whole breadth of the bridge. At Charing Cross side girders carrying transverse girders were used, and two columns were sufficient. At the Cannon Street Bridge the whole of the main girders ran longitudinally to the bridge. Roofs could be erected at various prices, even when of

the same span; but they might be constructed of such light or undurable materials, that in a short time they would be oxidized and rotted away, as had been the case in some roofs. There was no doubt, also, that the smaller the span the cheaper would be the roof: but he totally dissented from the opinion, that there was no use in getting rid of columns, for he believed that the value of having no columns might far exceed the additional cost of the roof. Take the Tithe Barn station at Liverpool, which was one of the earliest of the large stations he constructed; no columns were used there, but the whole width of the station was roofed over in one span, and as the traffic increased, the lines and platforms were moved and modified, so as to enable treble the amount of traffic to be carried on. That would have been impossible if the roof had been built with columns; and he had no hesitation in saying, that the Company had been repaid the increased cost of making the roof of that station in one span many times over. The question had been fully considered in reference to the Charing Cross and the Cannon Street stations, and he came to the conclusion that intermediate columns ought not to be used. He believed the value of those stations would have been greatly diminished, if they had been divided into bays with columns, for the sake of reducing the price of the roof. He had generally allowed, in addition to the weight of the trusses, 40 lbs. a square foot for the covering and pressure of the wind.

Mr. J. W. Barry, in reply upon the discussion, said that he entirely concurred in the observations as to the inadvisability of employing columns between the platforms or lines. He thought any one who, after considering the great value of the space enclosed within the walls of those two stations and the enormous cost of the land, looked at the plans, would see at once, from the way in which the platforms were necessarily disposed, the great difficulty there would be in putting columns in positions which would not be objectionable. It was difficult to come to a sound conclusion regarding the prices of roofs, square for square, because the mode of construction, and consequently the cost, varied considerably in different positions and under different circumstances. For instance, in the St. Pancras roof, wooden sash-bars were employed, while at Cannon Street and Charing Cross the sash-bars were of iron. Any one who had been present at the recent fire at Charing Cross station must have owned that the iron sash-bars were preferable; and certainly, in this instance at least, the iron sash-bars might be taken to have well repaid the cost of their adoption. At Charing Cross and Cannon Street stations the position of the streets prevented the employment of any side abutments to sustain the thrust of the roofs, which therefore had to be self-contained. The price of iron was comparatively high at the time the roofs were made; and moreover, as was ex-

pressly stated in the Paper, the cost given was the actual cost of the work as executed, and included every possible item of charge. He thought the proper object of Engineers was to make useful and commodious structures, taking advantage to the utmost of the land at their disposal, which, in situations similar to those under discussion, had been acquired at such great cost. So far as Cannon Street and Charing Cross were concerned, these objects, he thought, had been carried out.

It only remained to say, that when Mr. Ryde estimated that the rent of the arches, capitalised at twenty years' purchase, would pay for the cost of the viaduct, his remarks applied to railways which passed through crowded neighbourhoods, and not to railways like the Greenwich Railway, which for a long distance traversed fields and market gardens.

Mr. Gregory, President, observed that any engineer who had inspected the Charing Cross Railway and the City Terminus Extension of that line must have been struck with the admirable execution of the works. Undertakings of such magnitude and such character ought to remain on record; and he much wished that engineers generally would emulate Mr. Hawkshaw and his assistants, by giving Papers descriptive of the other Metropolitan lines. Accounts of the works of the underground railways of London, from their Past President, Mr. Fowler, or some of the gentlemen connected with him, would be especially appreciated. Upon such Papers there would be an opportunity of discussing the question suggested by Mr. Ryde, as to the comparative merits and cost of underground and overground railways. A good deal might be said on both sides. It had often been urged, with a certain amount of *primâ facie* good reason, that by making them to a great extent under roads, underground railways were much cheaper; but it was one of those subjects which ought to be exhausted not merely by speculation, but by practical illustration.

He was glad that the Author had adopted the suggestion to give the exact cost, and not the analysed and reduced cost; because all matters which were part and parcel of the cost of a railway ought to be considered by the engineer, particularly looking to the important element of the profit of a work. He had been pleased to hear that the local traffic alone between Charing Cross and Cannon Street produced $2\frac{1}{2}$ per cent. profit on the outlay; but he was afraid, if all the extension railways running into the Metropolis were looked at, they would not be found generally to have been so successful. One of the questions which engineers were bound to consider was the financial results of their various operations.

It had been observed, in reference to a statement as to the cheap cost of the Birmingham roof, that at the time that roof was

made, the price of iron was very low, and it had been stated that the price now was still lower; but it should be remembered that when the Cannon Street and the Charing Cross stations were built the price of iron was high. The price of ironwork was given in the Paper as £25 a ton when the Cannon Street roof was constructed; and, in making comparisons of roofs of different styles of construction, the important element of the cost of the raw material ought not to be forgotten.

April 7, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Walthew Clarence Barton, James Bower, William Welham Clarke, Richard Smith Clayton, Francis Jellanus Dennys, James Mathias, John Paton, George Lowe Reid, and David Richmond, as Members; Herbert Goulburn Anderson, Frederick Cadogan Barron, William Thomas Blacklock, Walter Raleigh Browne, Richard Henry Brunton, Charles Townshend Casebourne, Robert George Clutton, Charles Hutton Croudace, Henry Algernon Shrapnel Fenner, William Randolph Innes Hopkins, William Stuart Howard, Alfred Longsdon, *Sir* Arthur William Mackworth, *Bart.*, R.E., Robert Reynolds, Francis William Robinson, Robert Brough Smyth, William Sykes, James John Wallis, and David William Young, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Section IV. of the Bye Laws, as Students of the Institution:—James Alston Carfrae, John Malcolm Gibson, Charles Selwyn Harris, George Edward Page, and Frank George Wynne.

No. 1,184.—"On the Experimental Determination of the Strains on the Suspension Ties of a Bowstring Girder." By Wilfrid Airy, Assoc. Inst. C.E.

In this Paper the case of a bowstring girder, as ordinarily constructed, only is considered; but the principle on which the strains have been ascertained applies equally to other instances of mechanical structures with complex bracing, where the labour and uncertainty of a theoretical calculation render an experimental investigation exceedingly desirable. The mathematical investigation, for instance, of an iron arch distorted by a weight—which is the case in the example here investigated—is extremely laborious, and the problem can only be solved approximately.

The model on which the experiments were made was as follows, Figs. 1 and 2, Plate 18:—The bow was of steel $\frac{3}{8}$ inch square,

span 6 feet, rise 1 foot; the string was constructed of two slips of oak each $\frac{3}{4}$ inch deep by $\frac{3}{8}$ inch wide. These two slips were $\frac{5}{8}$ inch apart, and embraced at each end a small block of oak, to which they were rigidly fastened, and into which the two ends of the bow were let and wedged up. The suspension ties were of steel-wire gauge No. 6 (96 feet to the ounce); these wires were attached at the top to strong loops rigidly fastened to the bow, and at the bottom to the eyes of small eyebolts, which passed between the two slips composing the string, and were secured by nuts to small wooden blocks nailed at each joint on the under side of the string. By means of these nuts each tie could be accurately adjusted as to tightness.

As the question of the distribution of the strains on the suspension-ties depends materially on the relative stiffnesses of the bow and string, it is of importance, for arriving at any principle on the subject, that these should be known. The bow and the string were accordingly tested separately. The bow being set on end vertically sagged $\frac{5}{32}$ inch from its span, when lying flat on a table, by its own weight, and deflected further, pretty uniformly, at the rate of $\frac{3}{32}$ inch per lb. hung from the top. Again, a straight piece of steel, of the same section as the bow, being laid on two supports 6 feet apart, deflected uniformly at the rate of $\frac{5}{32}$ inch per lb. laid on at the centre. The string being laid on supports 6 feet apart deflected uniformly at the rate of $\frac{1}{4}$ inch per lb. laid on at the centre.

The process by which the tensions were ascertained is as follows: the ties, which were constructed of thin steel wire, gave, on being sounded, a good resonant musical note; and advantage was taken of this to compare the note of any string with that of a free string suspended in a frame made for the purpose, and cut off by a sliding bridge to the length of the string under comparison. The free string supported a small scale-pan, and this scale-pan was loaded with weights till the note of the free string and that of the string under comparison exactly coincided. This was determined by ear with the greatest accuracy, the effect of $\frac{1}{2}$ oz. in 80 oz. being clearly perceptible, and consequently the tension of the string on the girder was measured by the weight in the scale-pan of the free string:— and this was done for every string in every case.

The determination of the thrusts, which at first appeared a great obstacle, was reduced to that of determination of tensions by the following expedient: it was observed that the effect of a uniformly distributed load was to throw all the strings into tension. The girder was therefore loaded with a heavy uniform load, and the travelling load was then applied in addition; the effect of the travelling load would be to increase the tension of some of the strings and to diminish that of others, but so long as the tension on every string produced by the stationary load was greater than the thrust

produced by the travelling load the string would remain in tension, and its tension could be estimated as above described.

Consequently it will be seen that the recorded tensions and thrusts, which would be produced by a single weight at various distances along the girder, are the results of a differential process: thus, a uniformly distributed weight is applied on the girder, and the tension of every string is taken; then a travelling weight is introduced in addition and hung at any one point, and the tension of every string is again taken; the difference of the tensions in the two cases of each string is taken as the thrust or tension of that string produced by the travelling load.

The reduced results of the experiments are shown on Plate 18, Figs. 3—14; the tensions and thrusts are given in ounces, the thrusts being distinguished by the letter T.

The results thus obtained comprise the effect of every possible arrangement of loads that can come on a girder—for the effect of a load at any one point is given on the diagrams, and the effect for a combination of loads at different points may be obtained by combining the strains (with their proper signs) of the separate cases. For it has been verified by experiment—

1st. That the tension, or thrust, of every string is proportional to the weight causing it;—thus, if a single weight hung at any one point produces on any one string a certain tension, a weight of double the amount will double the tension on the same string.

2nd. That when several weights are applied at the same time, the effect on every string is that due to the sum of the effects which would be produced by each of the weights separately. This has been proved by experiment, and holds good even for the extreme case of a uniformly distributed load.

For the important case of a uniformly distributed load the strains are given on the diagrams; and it now remains to deduce from the experiments the rules by which the strength of ties should be regulated:

A. For an evenly distributed stationary load.

1st. All the bars are in tension.

2nd. The end uprights are most strained and the middle ones least; the end ones take about three-fifths and the middle ones about two-fifths of the load due to a bay.

3rd. With respect to the diagonals—those are most strained which radiate outwards from the points where they meet the string, and the strain on each of these may be taken at one-half the load due to a bay: those that radiate inwards from the points where they meet the string are strained to the extent of one-fourth the load due to a bay.

B. For a single moveable load.

1st. The uprights are liable to a tension of from $\frac{10}{34}$th to $\frac{1}{6}$th of

the weight as the load advances from either end towards the middle: —they are liable to a most insignificant amount of thrust, which may be absolutely neglected as a practical question.

2nd. With respect to the diagonals—the greatest tension to which they are liable is $\frac{1}{4}$th of the weight, and the greatest thrust is $\frac{2}{3}$ths of the weight: with the exception of those very near the end of the girder, all the diagonals will be liable to strains approaching the above as the load moves along, and it will not be worth while to make any of them weaker than required by the above strains.

As affecting the construction of the ties, it should be noticed (as before stated) that the bars liable to thrust are the diagonals, and these should be stiffened to resist the thrust:—the uprights need not be stiffened, as the degree of thrust to which they are liable is quite insignificant.

The following formula may be usefully deduced from the experiments:—

1. If the total stationary load, exclusive of the weight of the bow, be $5\frac{1}{2}$ times the weight of the single moveable load, none of the bars will ever be in thrust.

2. If the stationary and moving loads be each represented as a load per foot run, then the condition that must hold, in order that none of the bars may ever go into thrust, is—exclusive of the weight of the bow—stationary load per foot run = 1·73 × moving load per foot run; and this formula would hold very closely for all spans up to 200 feet.

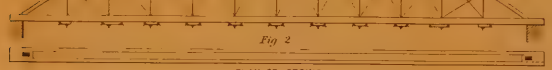
All the experiments and results recorded in the present Paper refer strictly only to the model experimented upon; but from some experiments previously made upon a similar girder with a different number of bays, the Author can state that the results agreed closely with the general proportions given above under A—B.

The Paper is illustrated by a series of diagrams, from which Plate 18 has been compiled.

STRAINS ON BOW STRING GIRDER.

Fig 1.

Fig 2



PLAN OF STRING.

Fig 3

Fig 4

Fig 5

Fig 6

Fig 7

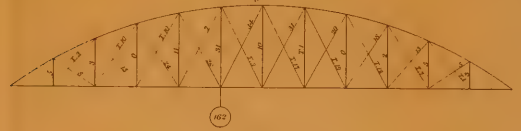


Fig 8.

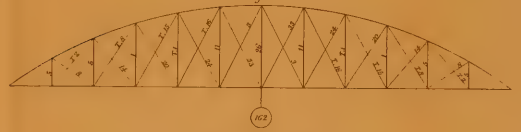


Fig 9

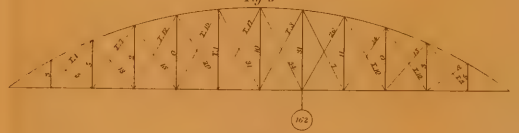


Fig 10.

Fig 11

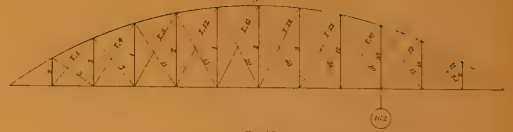


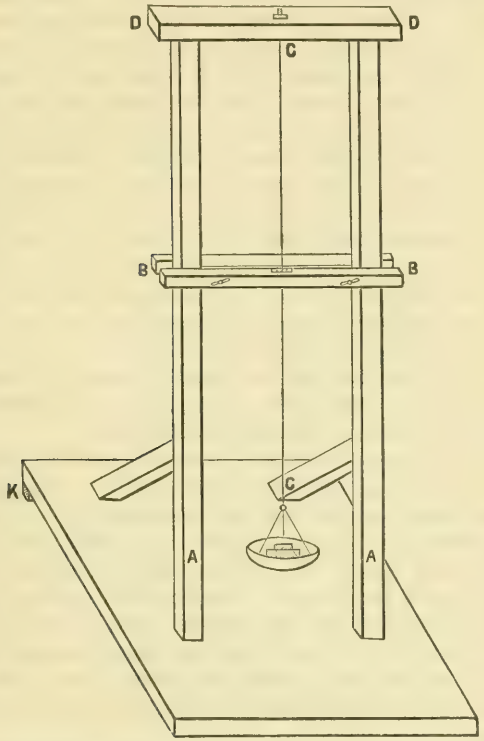
Fig 12

Fig 13

Fig 14.

APPENDIX.

MONOCHORD FRAME FOR COMPARISON OF MUSICAL NOTES.



AA. Upright legs of frame graduated with inches and parts, measured from the upper end of the wire.

BB. The sliding bridge, which can be moved up or down the legs AA, and clamped fast in any position.

CC. The comparison wire, made of the same material as the ties of the girder: it can be cut off to any required length by the sliding-bridge BB, and weighted to any required tension by means of weights laid in the small scale-pan.

K. A small block running under the back edge of the base, so as to tilt the frame slightly forwards, and cause the wire to bear steadily, though lightly, against the sliding-bridge.

Mr. Airy remarked that the Paper was simply an accurate investigation in one single instance of a very difficult problem, and was not framed to exhibit a complete theory on the subject; but the principle on which the strains had been investigated, and which had been, in the present instance, successfully applied, was, he believed, novel, elegant, safe, and applicable to a great number of complicated structures, such as lattice-girders, station-roofs, and trussed arches. It was no unusual thing for an engineer, with an important or extraordinary work on his hands, to have a model made of the intended structure for the purposes of experiment, if it was thought that thereby results might be arrived at affecting the security and expense of the work. This, then, was what had been done in the present instance; he had shown how such a model could be constructed, so as to obtain important results, which could scarcely be obtained except by direct experiment. The reasons which led to the selection of the instance in question were these:—He was engaged on the calculation of the strains on the different parts of a bowstring girder; and after easily determining the strains on the bow and on the string, had found himself totally at a loss for a correct or reliable method of determining the strain on the ties, and, by reason of the difficulty of the theoretical investigation, had found himself driven to adopt the experimental method described in the Paper.

Mr. W. H. Barlow said, the process described was at once novel and interesting, but the experiment only applied to a particular construction—a steel top with a wooden tie-bar. As in practice steel bowstring bridges with wooden ties were not used, he did not know to what extent the tensions that might arise on the different parts would be affected. No doubt the principle would be applicable for ascertaining the strains upon girders made of the same metal throughout; but he was not sure whether the tensions exhibited on the diagrams would be correct, if they were intended to be applied to any other than the identical structure alluded to in the Paper.

Mr. Airy replied that the principle was applicable to any complicated structure. He could not say that the experiments would be at all affected by employing a steel or iron string; it would simply make the difference of a little stiffness, and he did not believe it would affect the operation in any degree.

Captain H. W. Tyler remarked, that in the diagram (Plate 18, Fig. 14), which represented a beam loaded with 52 lb. weights distributed along it, the strain in tension on the middle upright was marked 19, and the strains on the uprights on each side of it were marked 21; while the strains in tension then went down again, in succeeding uprights on either side, to 19, and afterwards increased towards the ends to 26, 29, and 30. He should be glad

to learn how it was that these strains did not decrease regularly towards the middle of the girder. Similar irregularities were observable in the strains marked on the diagonal braces.

Mr. AIRY could only say that the strains put down in the diagram, although they ran very curiously, were nevertheless correct. They were not only the results he had obtained from compounding all the separate weights at different points; but they were also the results he had got directly from three sets of weights. He had hung one set of weights and taken the tensions of every string; he then hung another set and took the tensions, and again with the third set; and the increments for the last two sets were equal. Provided all the wires were in tension at the time of introducing the additional load, the precise amount of the tension on each was not essential to the problem; this, he thought, would be more clearly seen if he described the entire process: The wires were each separately secured to the string by a small screw-bolt and nut; and before any weight whatever was hung upon the girder, every wire was just drawn straight by its nut, and, as nearly as could be judged by touch, they were all drawn equally. It would be readily seen that in this condition they would be all quite slack, there being no weight for them to pull against; then a uniformly distributed weight was applied on the girder, and all the wires would at once go into tension, as he had observed. This was merely an artifice to throw everything, by a natural process, into a measurable state of tension, and it was neither assumed, nor likely, that the wires would each have the exact strain which it would have had if the wires had been all in precisely the same condition of strain, or rather of freedom from strain, before any weight was applied. After the aforesaid uniformly distributed load had been applied, and all the wires had gone into tension, the tension of each was taken as stated in the Paper; and then a travelling weight was introduced in addition, and hung at some one point, and the tension of every wire was again taken, and the differences + or −, as the case might be, were quoted as the tensions or thrusts due to the additional weight. The actual and correct strains, due to a uniformly distributed load, as given on the diagrams, were found precisely in this manner, by using a uniformly distributed load as the additional weight, and taking the tensions on every string before and after its application; and the difference of the tensions for each string was taken as the tension due to the additional distributed load.

Mr. J. T. HARRISON remarked, through the Secretary, that when the load was evenly distributed, the strains were considered anomalous and different to the strains as ordinarily provided for in designing similar girders. The Author truly described the strains on the suspension-ties as resulting from "an iron arch

distorted by a weight;" and in the word "distorted" was the clue to an explanation of the apparent anomalies. Were the bow uniformly compressed, and not distorted by the load, the strains upon the suspension-ties would give very different and more uniform results.

It might seem probable that the string of the girder acted in this case (Plate 18, Fig. 14) simply as a tie-rod, and that it supported very little if any of the weight applied: this did not, however, appear to be the case, as on resolving the strains on the diagonals, and adding the vertical resultants to that on the vertical tie-rod, the following results ensued, which showed that 34 parts of the weight (572) attached were borne by the string of the girder. Of these, 33 parts were thrown upon it immediately adjoining the springing of the bow. Throughout the remaining length of the girder, the string was strained transversely, in some cases relieving the tie-rods, in others adding to the strain upon them by extraordinary distortion transmitted through them from the bow.

This would be further considered (Plate 19, Fig. 4):—

Points of Application.	Weight applied.	Vertical Strain on Tie-rods.	Difference. +	Difference. −
a	52	35½	..	16½
b	52	49½	..	2½
c	52	54½	2½	
d	52	50	..	2
e	52	53	1	
f	52	53	1	
g	52	53	1	
h	52	50	..	2
i	52	54½	2½	
k	52	49½	..	2½
l	52	35½	..	16½
	572	538	8	42

Difference borne by bowstring = 34.

Showing 8 as the extra strain put upon the ties in places;
and 42 as the strain at other points taken off the ties;

leaving 34 borne by bowstring.

The action of the string was generally so insignificant, as affecting the strains on the ties, that for the present it might be disregarded, and the case might be considered simply as an arch springing from abutments O and R, subjected to a load evenly distributed, and applied by means of vertical and diagonal rods attached to the bow at equal distances.

Suppose the rods to be of uniform strength, and the points from which they were suspended to be immovable, the strain thrown upon each of them would depend upon the degree to which they

were respectively stretched in proportion to their length, the strain upon each rod varying inversely as its length and diminishing upon the diagonals as the angle of inclination from the vertical line increased. Thus if a weight were attached at A (Plate 19, Fig. 1), the junction of three tie-rods, suspended at B, C, and D to an inflexible beam, and the effect was to stretch the rods to E, the vertical tie would be the most extended, both in reality and in proportion to its length, and would therefore be strained most. The strain upon B E would be the next greatest in both these respects, and that upon D E would be the least. Should the beam, however, be either displaced or distorted, the conditions would be entirely altered, and with them the strains also.

If the beam were deflected from B D to B E (Plate 19, Fig. 2) a greater strain would be thrown upon the ties B F and C F, and the strain on E F would be diminished. If the beam were bent upwards, as B E D (Plate 19, Fig. 3), the chief strain would be thrown upon the vertical tie, and the strains upon the diagonals would be diminished; on the contrary, if the beam were deflected in the centre at C, the suspended weight would receive greater support from the diagonal ties, and the vertical would be relieved. All these varying conditions were exhibited in the bowstring girder upon which the experiments had been made by the Author.

The bow was an arc of a circle to which, in the first place, an evenly distributed stationary load was applied. Now it was well known that a segmental arch thus loaded would inevitably become distorted when the centres were struck, that it would sink at the crown and rise at the haunches. The Author seemed to admit that an iron arch was so distorted, and the experiments appeared to prove it. Had the bow formed a catenary curve, it would have been in equilibrium under a load which was uniform as the length of the bow: but whereas a catenary when under extension was in stable equilibrium, under compression its equilibrium was very unstable, and the least departure from the true catenary curve tended to general distortion. The bow experimented upon nearly coincided with a catenary of the same length.

Assuming distortion in the bow, in consequence of the application of the weights, viz., sinking at the crown and rising at the haunches, there would be two points about P and Q (Plate 19, Fig. 4) which would retain their relative positions to the fixed points O and R, from which the bow sprang. Then the curvature of the bow between P and Q would be diminished, and consequently the point f', as regarded e' and g', would be depressed, and the points d', e', f', g', h', would all be depressed in relation to the stationary points P and Q. At the haunches, the curvature of the bow between the points O and P, and Q and R, respectively, would be increased, the points b' and k' being elevated

to the greatest extent relatively to a', c', i', l', as well as to O, P and Q, R. Had the points e', f', g', sunk uniformly, the greatest strain would have been upon the vertical rod $f'f$, instead of which the strain on all three ties was similar, viz., 19. It did not appear easy to account for this on any other supposition than the relative depression of f' with respect to e' and g'. Again, the points e' and f' being depressed more than d', which was near the fixed point P, the strain was relieved from the diagonal attached to the bow at f', and thrown upon the ties ee' and ed'. The weight suspended at d was thrown chiefly upon the diagonal dc', in consequence of the elevation of the bow at the point c', and the diagonal de' was relieved as the point e' was depressed. Again, the strain caused by the weight at c was thrown equally upon the rods cb' and cc', as the points b' and c' were raised whilst the rod cd' was relieved by d' being somewhat depressed. The weight at b was thrown chiefly on the vertical tie-rod bb', as the point b' was raised to a greater degree relatively than the points a' and c'. There was only one diagonal at a, and the string of the girder evidently supported a large proportion of the weight suspended at that point. This seemed to explain generally the relative strains on the several tie-rods. It would, however, be a difficult problem to demonstrate the actual strain upon each tie. The first point to determine would be the distortion of the bow of given dimensions and material under a given load uniformly distributed. To determine the influence on the strains when the altered position of the points of suspension was determined was comparatively easy. It seemed probable that, as the distortion would increase with the weight applied, so the relative strains thrown on the ties would be increased or diminished proportionally with the distortion; but this was not borne out by the Author's experiments, from which it might be gathered that the strains on the ties were found to increase throughout uniformly in proportion to the weight applied.

The string of the girder evidently influenced the amount of strain on the tie-rods; in some cases it increased, in others it diminished these strains. It would be liable to distortion similar to that of the bow. Below the points P and Q its curvature would be reversed round some points near S and T. To this distortion the string would offer resistance in proportion to its transverse strength, which was greatly increased by the points of rest S and T virtually becoming points of support. But it by no means followed, that the curvature of the string would follow the contortions of the bow without offering resistance varying at different points. The difference in the resultant vertical strains on each side of the vertical points S and T was very striking—at c and i being $54\frac{1}{2}$, whilst at d and h they were only 50. This seemed to arise from the string at c being raised, by the rising of the haunches of the bow at b' and

Fig: 1.

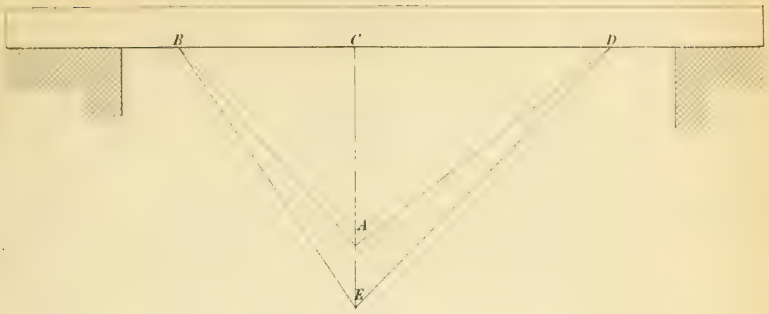


Fig: 2.

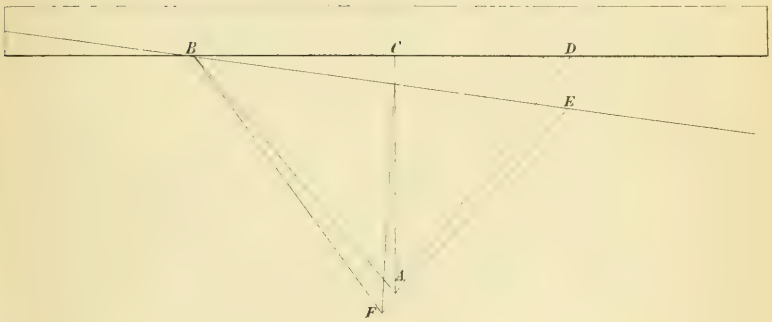


Fig: 3.

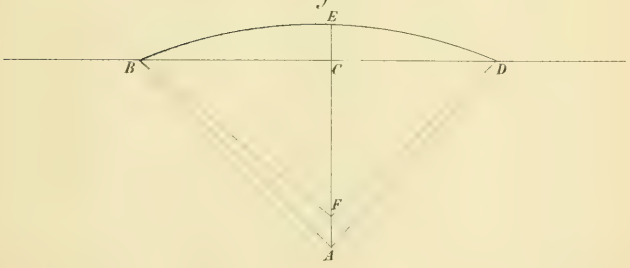
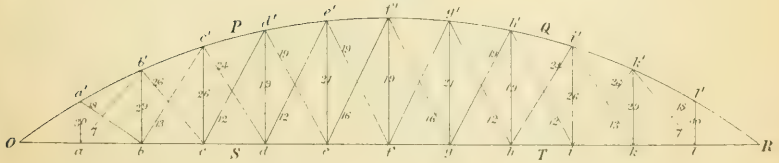


Fig: 4.



J.T. BARRY, N.1857 Messrs. [illegible] The Institution [illegible]

c', more in proportion than it was lowered at d; the ties attached at c receiving an increased strain, whilst those attached to the point d were relieved by the girder-string bearing a portion of the strain. The increased vertical pressure at the three central points of suspension e, f, and g, was apparently accounted for by the string at those points being strained downwards more than the bow of the girder—a result very probable, as the points c and i, which were so near the neutral points S and T, would be considerably raised. The curvature which the string would assume at b and k seemed to be greater than that of the bow at b' and k', as the rods attached to b and k were relieved of a portion of the weight attached to them. A considerable portion of the weight suspended at a and l was evidently borne by the bowstring.

From these considerations it would result, that the bow of such girders as the Author had experimented upon should possess considerable transverse stiffness to prevent distortion; and that its curvature should be adapted to the load it was intended to support.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously:—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 21st of April."

April 21, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,193.—"On Irrigation in India."[1] By ALLAN WILSON, M. Inst. C.E.

THE lamentable loss of life caused by the late famine in India has demonstrated the necessity of providing for the regular irrigation of a large extent of land, to meet the periodically-recurring seasons of drought. This subject has for years past been pressed upon public attention, under every discouragement, by many influential advocates, foremost amongst whom must be mentioned Major-General Sir Arthur Cotton. His predictions as to the results that would follow the general adoption of a well-matured plan, in regard to the increased prosperity of the people, the development of the resources of the country, and the consequent augmentation of Government revenue, are now admitted to have been entirely fulfilled.

The Author, having had fourteen years' experience in the construction and superintendence of irrigation works in the central and southern provinces of India, where wet cultivation is extensively practised, proposes in this communication mainly to refer to that part of the empire. A brief description will in the first place be given of the former and present systems of irrigation, and of the accessory works, and the cost of providing the water will then be noticed.

The value of artificial means of irrigation, for increasing the fertility of the soil, was recognized in India at an early date. In the Punjaub, canals for this purpose, as well as for navigation, were constructed as far back as the middle of the fourteenth century. But it is in the southern parts of India, where the rainfall is more precarious, and the river supplies less easily available, that the most extensive works are to be found. It has been estimated that, prior to the establishment of British rule, there were, in fourteen of the principal irrigated districts of the Madras Presidency, upwards of forty-three thousand tanks and channels in repair, besides about ten thousand out of repair; having, probably, 30,000 miles of embankments, and three

[1] The discussion upon this Paper was taken in conjunction with the two succeeding communications, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

hundred thousand separate masonry works. Some of the tanks and reservoirs were on an immense scale, for irrigating many thousand acres, while there were smaller tanks, wells, and springs, which watered only a few acres. In a report made in 1853 by the late Colonel Baird Smith, of the Bengal Engineers, it is stated that "The Ponairy" tank "in Trichinopoly, with its embankment of 30 miles in length and probable area of 60 or 80 square miles, now lost to the community, and the Veeranum tank, with its 12 miles of embankments and 35 miles in area, happily still in full operation, and securing at this time, after an existence of almost fabulous duration, an annual revenue of 114,500 rupees, or £11,450, to the Government."

It is remarkable that the Government should have allowed so many fine works gradually to fall into decay, without replacing them by others; as great natural facilities exist for storing up water, and for forming canals to lead it on to the land. The irrigation works on the Godavery and Kistnah rivers, in the northern Circars, and on the Coleroon, in Tanjore, have only been recently completed. But many large rivers are still allowed to flow into the ocean, almost unused for agricultural purposes.

Intelligent natives, acquainted with the history of their country, often point to the fact, that in the North-west Provinces great suffering formerly occurred, on the partial failure of the monsoon, for want of sufficient reservoirs to store water, and channels to lead it on to the land; whereas, since the opening of the Delhi and Doab canals, and other works, the villages that come under their influence have been to a great extent preserved from the calamities of famine. The pressure of the dearth in the adjoining districts, and the consequent mortality and distress, have thus been lessened, and the whole population has greatly increased in prosperity and number.

The importance of even limited supplies of water for irrigation will be understood, when it is mentioned that a small quantity of water supplied to the seed-beds and early transplantings, in good time, enables the crop to take root sufficiently to withstand the heavy rains which usually fall in the first burst of the monsoon, and frequently prove injurious to the newly sown and planted crops, unless previously moistened by gentle waterings. Moreover, even small patches of irrigated land round the villages are invaluable to the people. It is found in seasons of drought, and consequent famine, that the cattle perish for want of food earlier, and it is believed in greater proportion, than the people themselves; and as the impoverished population seldom have the means of replacing their lost cattle, it often happens that when the season for preparing the ground for the seed comes round, it cannot be ploughed, and the distress is augmented by the land remaining uncultivated.

It is well known that one acre of irrigated land furnishes sufficient forage to feed the number of cattle required to plough from 10 to 20 acres of land: so that a village with 50 acres of such land can, even in seasons of drought, feed the cattle necessary for preparing 500 acres of dry land for cultivation under the rains.

A description of the existing system of irrigation, as carried out in Southern India, has been already given in the Report of the Madras Public Works Commissioners; so that the Author will at once proceed to refer to the most general and least expensive mode of irrigation, by means of artificial reservoirs, and to the methods adopted in forming such reservoirs. In selecting a site for a reservoir, it is essential to ascertain, in the first place, that the foundation is suitable; the next point to be determined is, the extent of land to be irrigated, and the quantity of water necessary for such irrigation. The area of the drainage or gathering grounds may be estimated from the trigonometrical survey maps of India, and the quantity of water which will pass into the tank during floods should be calculated according to the known rainfall, due allowance being made for absorption and evaporation. With these data, the dimensions of the different works can be fixed. It should, however, be borne in mind, that depth of water is of more importance than a large surface area, as the evaporation will be less in the former case. An examination should also be made of the valleys in the vicinity, with a view to ascertain whether the surplus water flowing through the tank during floods, could not be carried across intervening ridges, so as to fill a chain of tanks.

A tank is simply a reservoir formed by throwing an embankment, or bund as it is called in India, across a valley to dam up the drainage. The most simple description of bund is constructed entirely of earth, which is generally dug from the bed of the intended reservoir. Tanks of large dimensions have on their inner slope a pitching of loose stone, to prevent the embankment being injured by the action of the waves; and when stone is abundant, this revetment is from 18 inches to 2 feet in thickness,—the native workmen considering these dimensions the most economical as regards facility of building. The earth bund is constructed by a class of labourers known as 'tank diggers,' or 'earth-work wudders,' similar to the English 'navvy,' the earth being carried in baskets to the site and there deposited. Puddle is seldom, if ever, used; indeed it is not required, as owing to the lodgment of silt, a tank will puddle itself after it has been once filled.

Besides this embankment, some of the large Hindoo works have a massive retaining wall of masonry in front. Many of these walls are built of dressed stone, close-jointed, backed with rubble and a rough description of concrete; at intervals, bastions are sometimes thrown out, both to strengthen the masonry and for effect. Between

these buttresses a flight of steps of cut stone is constructed, to enable the natives of the place and pilgrims to perform their ablutions, as also to wash their garments. Behind this masonry the earth is thrown, in layers of from 9 inches to 1 foot in thickness, from baskets, the work-people walking over each layer both in going with their loads and on returning. If this is carefully attended to, a solid and substantial piece of work is obtained.

To obviate the danger of an excessive influx of water during floods, most tanks are provided at one end, and not unfrequently at both ends, of the embankment, or bund, with a waste weir (known in India as a calingulah), to allow the surplus water to escape after the tank has been filled. In constructing a tank, the discharge capacity of the calingulah is an essential feature. It should here be remarked that, whilst the native Engineers have generally shown great skill in combining simplicity with efficiency and economy, in the selection of the site and the construction of the work, they seem to have under-estimated the quantity of water to be carried off by this bywash; for it is found that many of the tanks which are now useless have been breached from no other apparent cause than the want of sufficient outlet to allow of the escape of the surplus water during floods.

These calingulahs are constructed of different forms and dimensions, according to the capacity of the tank, and the area of the gathering ground. They are built of rubble masonry, and are frequently of the form and size, as regards breadth and height, shown in Plate 20, Fig. 1. Where the nature of the ground will admit, some calingulahs are of still more simple construction, having merely a retaining wall at the end of the bund, which is returned to meet the face pitching. At right angles to this retaining wall, another wall is built, having its foundations about 18 inches below the surface of the ground, and raised to a height of 2 feet 6 inches, at which height it is carried level, until it meets the slope of the rising ground. These walls are in many instances built of rough stone only, and though this costs a mere trifle, they answer the purpose admirably. In the wall of masonry, upright stones are inserted, varying from 2 feet to 5 feet in height, and placed from 3 feet to 4 feet apart. When the rains are moderate, these spaces are filled up with straw, earth, or rubbish, in order that the capacity of the tank may be increased. When the rains are heavy, and fears are entertained for the safety of the bund, these obstructions are cleared away, so as to allow the water to escape, and they are afterwards renewed when it can be done with safety. But many of the ruined tanks appear to have been breached solely for want of these precautions, owing to the desire of the cultivator to prevent the escape of water.

The rule adopted by Indian Engineers for calculating the size of

these escapes is very simple. The velocity is ascertained by multiplying the square root of the height of the water above the opening by 5, and the height being in feet, the velocity will be in feet per second; this multiplied by the product of the height and length, will give the discharge in cubic feet per second. The formula $V = \frac{2}{3}\sqrt{H} \times 5.1$, where V is the velocity and H the height, is more applicable to rectangular apertures of from 1 foot to 2 feet, than for large openings like those of calingulahs.

In order to draw off the water for cultivating the fields, each tank is provided with one or more sluices. These sluices sometimes take the place of calingulahs, but this is rare. When the tank is of ordinary capacity, two sluices built at the lowest level are generally found sufficient; but when large, it is necessary to have several sluices, which are then placed at different levels. These sluices are exceedingly simple, both as regards their construction and the means employed for drawing off the water. They are simply tunnels built of brick or rubble, either arched at the top, or covered with flat stones. The floor is paved with well-jointed flags, and the side walls are lined with the same. The inner end, or head of the sluice or tunnel, is closed by stones, where the water enters, in which one or more orifices, generally from 3 inches to 5 inches in diameter, are cut. The water is shut off from, or let into, the tunnel by means of a conical plug of wood, attached to a long handle, by which the plug can be raised or lowered as required. To effect this a man has in most cases to go into the water, and is not unfrequently obliged to swim. Many of these sluice heads are provided with long, upright stones on each side, and between these are cross stones at suitable heights, having holes of proper diameter cut in them, so as to come precisely over the sluice orifice, through which passes the handle fixed to the plug for closing or opening the orifice. These orifices are in some cases too small, and in others too large, for the requirements of the cultivator; indeed, but little attention seems to have been given to adjust the size so as to discharge the quantity of water required for irrigating a given area of land.

At the end of the sluice tunnel below the bank, a cistern is generally built, having its sides and end pierced with holes at different levels, to enable the water to be taken to the fields at various elevations. Fig. 2, Plate 20, is a sketch of this sluice. This mode of drawing off the water has been found to answer so well, and is so thoroughly understood by the natives of India, that it is still generally adhered to when tanks require repair, or new sluices have to be built, provided the capacity of the tank will allow of its being adopted.

In order to show how favourable some parts of India are for forming reservoirs of large capacity, the Author would direct

attention to Fig. 3. This represents an artificial lake, which it is proposed to construct by damming up the gorge of a valley, to a height of 57 yards, with a depth of water of 54 yards at the embankment. This reservoir would be capable of storing upwards of 1,600 million cubic yards of water, and after allowing a due proportion for absorption and evaporation, there would remain sufficient to irrigate, at the rate of 3,500 cubic yards per acre, 240,000 acres of rice land; or, taking 500 acres per square mile as the proportion capable of cultivation, 480 square miles. Taking 170,000 acres as the extent of land to be irrigated for a single crop, this would require a discharge of 340,000 cubic yards of water per hour, by two sluices, one at each end of the bank, so regulated as to give this discharge under heads of pressure varying from 5 feet to 162 feet. As each sluice would require to be equal to the discharge of 170,000 cubic yards of water per hour, the Author would invite discussion as to the best description of sluice for discharging such a vast volume of water.

The sites for many of the anicuts, or masonry dams (also called weirs), thrown across rivers, have been so judiciously chosen by the native Engineers, that very little expense has been incurred in building them. The anicuts across the river Toombuddra (which forms the boundary between the Madras Presidency and the dominions of his Highness the Nizam), at a point where it is divided into two streams, by an island in the centre, and where the north stream has a dip of about 5 feet, may be mentioned as an instance in point. Between this island and the river bank, there are a number of small islands, composed of large blocks of granite and pieces of rock. All these have been utilised in constructing the anicut, which consists simply of boulders and blocks of granite thrown promiscuously together, to fill up the spaces between these natural aids. As will be seen by Fig. 4, the dam is most tortuous; and it will be observed by the section, that, whilst very little artificial work was required in constructing it, sufficient water has, nevertheless, been dammed up to cultivate a large area. The irrigation channel taken off from this dam is 25 feet in width, 3 feet in depth, with a fall of 1 foot per mile.

Anicuts are generally formed of boulders and stones thrown together. The side next the water dammed up has the outline of a retaining wall, with a slight batter; the stones are laid with some care, and have headers of great length inserted at intervals of from 5 feet to 10 feet; and the stones of the upper row at the edge next the water are bound together by iron clamps. On the lower edge of the apron, or on the down-stream side, two rows of stones, generally of large dimensions, are carefully laid by hand; and between the front and back walls loose stone is thrown. When this mass of loose stone has been raised to a sufficient height, the

top course is laid by hand, with large stones interspersed here and there, the interstices being hammer-pinned to prevent displacement during the floods.

Besides these weirs of rough stones the natives construct others of a temporary description. These consist of banks of sand, either run up the river for a considerable distance parallel to the bank, or obliquely across it to the opposite side, until a level has been reached where the lowest part of the bed of the river is higher than the mouth of the channel. As, however, these weirs require annual reconstruction, they become, in course of time, more expensive than the permanent constructions of rough stone, and are not now so generally used as they were formerly.

A more modern description of anicut, built on the Toombuddra, is shown in Fig. 5. It consists of a brick wall in front, having a considerable batter, and the rear wall is composed of granite blocks dressed on the bed, the end joints being laid in cement and carried up plumb; the space between is filled with broken brick chips and mortar—in fact, with concrete. The top is narrowed to 6 feet, and has a coping of granite 6 feet in length of various breadths, but never under 18 inches, and the thickness 15 inches. These coping stones are tied together with dowels in the front, and in the rear with iron clamps. A sluice has been built near one end, for the purpose of being opened during floods, to prevent as much as possible the lodgment of sand, silt, &c., which would necessarily occur were some such method not adopted. The river bed being of rock, the water falling perpendicularly over the weir has no effect upon the foundations of the building.

The natives have, as a rule, selected rock as the foundation for dams; and it is no doubt preferable to any other, both as regards economy and stability. A rock foundation is not, however, absolutely necessary, as has been fully proved under British rule in India, many works having been constructed on rivers, the beds of which consist entirely of sand. No better example of such masonry work could be found than the anicut across the Kistnah river, near the town of Beizwarah. The length of this anicut is nearly 3,800 feet, the breadth 300 feet, and the height in front is 21 feet above the deep bed, and 14 feet above the summer level of the water. It consists of a mass of rough stone thrown into the river, and allowed to assume its own slope. An interesting description of this wall will be found in a Report, made in 1853, on the Irrigation Works of the Madras Presidency, by the late Colonel Baird Smith, of the Bengal Engineers.

These masonry dams are, where practicable, taken advantage of for forming means of communication from one bank of the river to the other, by building a bridge on the top of the weir. Before constructing a masonry dam of this kind in India, it is essential to

make a close and careful examination of the country on each side of the river to be dammed up which lies below the site of the work. Sections should be taken, and all possible data obtained as to the rise of the river, in order to ascertain the height to which the dam can safely be raised. It happens, not unfrequently, owing to the dams being made without due allowance for the rapid rise of the river during the rains, that the banks above the dam are overflowed, and then the water finds its way down a valley studded perhaps with thickly-populated villages, thus causing a fearful loss of life and property.

It is necessary that these dams should have sluices at each end, and if requisite at other parts, to be kept open at times, so as to prevent the lodgment of silt above the weir, which might otherwise occur. A head-sluice should also be constructed, to enable the water in the river during a flood to be shut off, and so prevent sand from entering the irrigating channel. In cases where no head-sluice has been provided, a sluice is constructed at some convenient bend on the down bank of the channel, which, being opened during floods, to a certain extent answers the same purpose, Fig. 6. A head-sluice constructed by the Hindoos at a distant date, on one of the channels taken from the Toombuddra, is shown in Fig. 7. The sluice is not built immediately at the point where the channel is taken from the river above the anicut, but where the irrigating canal is taken off from the feeder which is carried round from the dam. When this sluice is shut during floods, the one across the feeder is left open, and after the monsoon it regulates the supply of water required for irrigation. This sluice is constructed of cut stone backed with rubble. The openings are three in number across the feeder, and two across the irrigating channel, each 10 feet wide, floored with substantial granite flags laid on rubble.

Across these sluice openings, and about 2 feet from the face, a couple of beams of timber are built into the abutments and piers, at a distance of 4 inches apart. In this space the wooden shutters, consisting of teak-wood planks from 6 to 9 inches broad, and 3 inches thick, are placed. This native system of closing sluices has been found to act so well, that it has been adopted more or less by English Engineers.

Besides these head-sluices, small openings are made at suitable distances in the bank of the channel, for the purpose of carrying the water to the fields to be irrigated. These are generally of a primitive description, being in most cases closed with clay or mud, which is objectionable, as the clay is not unfrequently washed out, and the water allowed to run to waste. The water from these channels, after irrigating the land in its course, is often employed to fill large tanks, so that a supply is secured for the crops during the hot season. Fig. 8.

In concluding these remarks upon channel irrigation, it may be

stated that great difficulty has always been experienced for want of a system for regulating the supply of water to each cultivator. Many disputes and bickerings consequently occur between the ryot, the revenue officer, and the engineering department, resulting in a prodigal waste of water. It is therefore desirable that some definite measure should be laid down by Government for the distribution of the water from all irrigating channels.

Great differences of opinion exist in respect to the cost of storing and distributing water over the land requiring to be irrigated; and, owing to the diversities of the revenue system, the results realized in various parts of India do not agree. The cost of forming a reservoir, with embankments, sluices, waste weir, &c., may easily be estimated; but not the cost of the distributing channels for conveying the water from the reservoir to the fields, which are often partly formed by the ryots themselves.

It could easily be shown, and will perhaps be generally admitted, that the cost of storing water is much less in the case of a large work than in that of a small one. In a report made by Colonel Dickens in 1855, on the Shahabad district, the estimated cost of storing and supplying water from four different tanks, including the cost of the distributing channels, was 400, 352, 350, and 494 cubic yards per rupee respectively. This gives an average of 400 cubic yards per rupee: and a cost of 8 rupees 12 annas per acre irrigated with 3,500 cubic yards. In 1862 Capt. Haig, the engineer in charge of the Godavery works, stated that the cost of the water required for lockage, evaporation, and absorption, would be about 1 rupee for 500 cubic yards, and he estimated the quantity necessary to maintain a discharge of $1\frac{1}{2}$ million cubic yards per hour, and afford a depth of 5 feet for navigation, at 4,089,200,000 cubic yards.

Colonel Rundall, of the Madras Engineers, states the rates per acre in the Madras presidency at 6 rupees and 8 rupees 3 annas; thus giving apparently an average of 7 rupees 15 annas per acre as the cost of storing water; but it does not appear whether the cost of the engineering establishment and of the distributing channels is included in these rates.

The Author can state, as the result of personal experience, that a few years ago, in the south of India at least, an extensive area in the immediate vicinity of the reservoir could have been provided with irrigation works, including distributing channels, at a cost of 10 rupees (£1) per 3,500 cubic yards. Owing to the increase that has of late years taken place in the rates of all kinds of labour, the cost would now probably amount to 15 rupees per acre irrigated.

Various opinions exist as to the quantity of water required for irrigating an acre of land. It must of course depend upon the locality, soil, rainfall, state of the atmosphere, and nature of the crop to be watered. As rice is the main food of the natives of Lower Bengal and the southern parts of India, the quantity neces-

sary for a rice crop may be assumed as the general average. From careful personal observation, the Author can state that, with good management, 3,500 cubic yards per acre is ample to raise a good, indeed more than an average rice crop. Common grains require only about one-third of this quantity, say, 1,300 cubic yards for each crop; whilst sugar cane, which of all crops requires the most water, took on an average 8,000 cubic yards per acre. These calculations provide for unavoidable waste, as well as for evaporation, which, of course, varies in different parts of India. The annexed table, giving the results of a series of observations on evaporation, taken at the Red Hills, near Madras, during five of the hottest months of the year 1844, will illustrate this important point.

ABSTRACT OF OBSERVATIONS ON EVAPORATION DURING THE MONTHS OF APRIL, MAY, JUNE, JULY, AND AUGUST, 1844.

1844 April.		1844 May.		1844 June.		1844 July.		1844 August.	
Date.	Evaporation in inches.	Date.	Evaporation in inches.	Date.	Evaporation in inches.	Date.	Evaporation in inches.	Date.	Evaporation in inches.
1	0·3018	1	0·4166	1	0·3927	1	0·4052	1	0·3478
2	..	2	0·4557	2	0·0000	2	0·2662	2	0·4052
3	..	3	0·4328	3	0·6011	3	0·3628	3	0·3877
4	..	4	0·4349	4	0·5545	4	0·3794	4	0·4564
5	0·3018	5	0·2454	5	0·5475	5	0·3873	5	0·3823
6	0·3432	6	0·5131	6	0·4176	6	0·3565	6	0·4102
7	0·3636	7	0·3996	7	0·4018	7	0·2608	7	0·3187
8	0·3158	8	0·2144	8	0·3574	8	0·4351	8	0·3103
9	0·3409	9	0·2847	9	0·3823	9	0·4347	9	0·3178
10	0·3467	10	0·3863	10	0·4060	10	0·3815	10	0·3282
11	0·3850	11	0·4019	11	0·4717	11	0·3781	11	0·3811
12	0·4424	12	0·4162	12	0·4073	12	0·3141	12	0·3769
13	0·4345	13	0·4495	13	0·4209	13	0·2579	13	0·3074
14	0·4085	14	0·4769	14	0·3532	14	0·2854	14	0·2987
15	0·0000	15	0·0000	15	0·2895	15	0·3503	15	0·3478
16	0·4274	16	0·3157	16	0·1922	16	0·3877	16	0·3632
17	0·5364	17	0·3112	17	0·1747	17	0·2879	17	0·3224
18	0·4611	18	0·2633	18	0·3561	18	0·2279	18	0·3769
19	0·4041	19	0·3715	19	0·4717	19	0·1198	19	0·3594
20	0·3987	20	0·2450	20	0·3752	20	0·2929	20	0·4064
21	0·4532	21	0·3195	21	0·2429	21	0·2055	21	..
22	0·4199	22	0·3686	22	0·4189	22	0·2937	22	..
23	0·4807	23	0·4089	23	0·4364	23	0·2808	23	..
24	0·4549	24	0·4601	24	0·5300	24	0·3303	24	..
25	0·4819	25	0·4048	25	0·3948	25	0·2929	25	..
26	0·4883	26	0·4364	26	0·4127	26	0·2974	26	..
27	0·3218	27	0·3806	27	0·4551	27	0·2933	27	..
28	0·3987	28	0·3453	28	0·4717	28	0·3927	28	..
29	0·3896	29	0·3648	29	0·4975	29	0·4684	29	..
30	0·4060	30	0·2891	30	0·3224	30	0·4285	30	..
		31	0·3719			31	0·2929	31	..
Means .	0·4082		0·3729		0·4058		0·3257		0·3600
Rain in inches	0·0000		0·082		0·1868		0·2279		0·1767

The mode of preparing land for wet cultivation is by laying it out in squares, rectangles, &c., each plot being surrounded by mud walls of sufficient height and thickness to prevent percolation or overflow of the water when it is turned on. These squares or rectangles are kept level, and are as large as the nature of the ground will admit. When one is sufficiently flooded, the water is let off at one of the lower corners of the field into the next division, and so on until the whole area has been irrigated. As a general rule, the land to be irrigated is under the tank embankment, extending inland from each side of the river, across the bed of which the embankment has been thrown (Fig. 3). The water is let off by sluices, through tunnels under the embankment, and is carried forward at a high level, by means of a canal of sufficient section to convey an adequate volume of water to irrigate the required area. Subsidiary or distributing channels are taken off at suitable distances from the main channel, the section of which is gradually decreased, until in the last reach only enough water remains to supply the wants of the last distributing channel. The sections of the subsidiary channels are also decreased in the same way.

Water is generally raised from wells, banks of canals, and rivers for irrigation purposes, by means of a môt, or picottah, and from springs by basket scoops. In Central India the môt, worked by two bullocks, is in general use for lifting water to nourish the spring crops and seed-beds for early transplanting. The môt (Fig. 9) consists of a leather bag fastened to an iron ring, and attached to a rope carried over a pulley fixed to two upright pieces of timber, securely built into the retaining wall of the incline down which the bullocks have to walk. At the small end of this bag another rope is fastened, which is carried over a roller at the foot of the upright timbers, and then over a pulley fastened on the incline. These ropes are then made fast to the yoke of the bullocks, and these are driven down the incline to haul the bag to the top. When the bag has been let down into the well, and is filled with water, it is drawn up by the bullocks to a certain height; the driver then sits on the lower rope, and by a sudden jerk brings the small end of the bag over the roller, so that when the bullocks have gone the required distance, the bag is at full stretch, and the water empties itself into a cistern, from whence it is carried in a duct to the ground requiring to be watered. After emptying the bag, the bullocks are backed up the incline, when the bag sinks into the well, is again filled, and hauled up. Sometimes two pairs of bullocks are used, and this is a better method when the farmer can afford to adopt it, as the bullocks are not then backed up the incline, but one pair is walking up the drive, whilst the other is coming down and pulling up the bag. This system is seldom adopted for field cultivation, the

expense being too great. The Author found, by observing the working of one of these môts in his own garden, that when the water had to be raised to a height of 22 feet, a pair of good well-fed bullocks could, with a smart driver, raise eighty-two bags of water in an hour. The working time in the morning was four hours and a half, and as the môt contained $4\frac{1}{4}$ cubic feet of water, the discharge per hour was $348\frac{1}{2}$ cubic feet, amounting for the morning's work to $1{,}568\frac{1}{4}$ cubic feet.

The picottah pump (Fig. 10) consists of a stout, upright post, firmly secured in the ground, over the top of which a lever is fixed. To the one end of this lever a bamboo of the length required is fastened, and to the other end a balance weight; and an iron bucket, containing a little more than a cubic foot of water, is hooked on to the bamboo. The picottah is worked either by one or two men: when by one man, the balance-weight lever is made use of, so as to enable the man to empty the bucket with greater rapidity and more ease to himself. When two men are employed, one works the lever by walking up and down it, and the other empties the bucket when raised (Fig. 11).

In baling out water for the foundations of a bridge, the Author adopted three systems, the picottah, worked by two men, others by one man, and basket scoops. These scoops consist of a basket, made of strong bamboo matting, formed into the shape of a triangle, worked with hand ropes attached to each corner, and to the point of the triangle, or bottom of the basket, Fig. 12. With the picottah, worked by two men relieved every hour, and a lift of 8 feet, twelve lifts per minute were obtained. This gave 720 cubic feet of water raised every hour, or 7,200 cubic feet per day of ten hours. At night the number of lifts per minute varied from eight to ten, and the average discharge per hour was 500 cubic feet, or 7,000 cubic feet for fourteen hours, and a total of 14,200 cubic feet raised per day of twenty-four hours. The picottah worked by one man raised the water to a height of 6 feet, with a relief every half-hour. Five hundred and fifty lifts were obtained per hour during the day, and four hundred and eighty during the night, the total quantity raised in twenty-four hours being 12,360 cubic feet. In the case of basket scoops, the water had to be raised 3 feet 9 inches, with a change of men every two hours. There were twenty such baskets at work, and they were each discharged on an average twenty-two times per minute, or thirteen hundred and twenty times per hour. Each basket contained $\frac{1}{3}$ cubic foot of water, and thus the total quantity raised in fourteen hours was 19,080 cubic feet. It was not found advantageous to bale water by this method during the night.

Water can be raised to any height, by increasing the number of scoops and regulating the height of each lift according to circumstances. The Author has had water raised to a height of 90 feet

in this way; but the cost when raised beyond a single lift becomes so enormous, that few cultivators can afford to adopt it, except in seasons of great drought, when, in order to save the lives of their cattle, a small patch of land must be irrigated at almost any cost.

STATEMENT OF THE QUANTITIES AND COST OF WATER RAISED BY NATIVE METHODS IN DIFFERENT PARTS OF INDIA.

MADRAS.

From "Madras Engineer's Papers," Vol. II. (1846).

Methods used.	Height raised in Feet.	No. of Men or Bullocks Employed.		Lifts per Hour.	Cubic Feet.		No. of hours' labour.	Total performance in the time.	Effect of Labour.		Remarks.
		Men.	Bullocks.		Per Lift.	Per Hour.			Raised one foot high during the period at work.	Delivery per rupee raised one foot high.	
								C. F.	C. F.		
Basket Scoops .	10	6	..	1,320	$\frac{1}{3}$	440	6	2,640	26,400	28,160	
Bullock Mot .	20	1	2	90	4·15	372	1	372	7,440	..	Best Cap.
Picottah . . .	10	2	..	600	$\frac{5}{6}$	500	6	3,000	30,000	96,000	

UPPER INDIA.

From "Indian Engineering," Vol. I.

Basket Scoops .	5	2	..	20	$\frac{1}{3}$	400	8	3,200	16,000	64,000	
Bullock Mot .	40	1	2	71	3	213	8	1,704	68,160	109,056	
Picottah . . .	16	1	..	180	0·45	81	8	648	10,368	41,422	

CENTRAL INDIA—AUTHOR.

Basket Scoops .	$33\frac{3}{4}$	4	..	1,620	$\frac{1}{3}$	540	14	7,560	28,250	31,285	Day.
Bullock Mot. .	22	1	2	80	$4\frac{1}{4}$	340	$4\frac{1}{2}$	1,530	33,660	38,468	Morn.
Picottah . . .	8	4	..	720	1	720	10	7,200	57,600	79,200	Day.
Picottah . . .	8	4	..	500	1	500	14	7,000	56,000	74,000	Night.
Picottah . . .	6	2	..	550	1	550	10	5,500	33,000	88,000	Day.
Picottah . . .	6	2	..	490	1	490	14	4,860	45,160	60,213	Night.

Extracted from the "Calcutta Gleanings in Science," Vol. I. (1830.)

Basket Scoops .	10	5	..	1,200	0·33	400	6	2,400	24,000	38,400	
Bullock Mot. .	11	2	1	44	1·75	77	6	462	5,082	8,131	
Picottah . . .	11	1	..	800	0·50	400	8	3,200	35,200	187,400	
Basket Scoops .	45	50	..	1,200	0·33	400	6	2,400	108,000	17,280	
Bullock Mot .	45	3	2	32	1·75	56	12	672	30,240	26,880	
Picottah . . .	45	6	..	800	0·50	400	12	4,800	216,000	289,666	
Basket Scoops .	45	100	..	1,000	0·33	332	12	3,948	177,660	14,212	

COMPARATIVE STATEMENT AT TEN HOURS PER DAY.

	Madras. C. F. raised 1 foot.	Upper India. C. F. raised 1 foot.	By Author. C. F. raised 1 foot.	Calcutta Gleanings. C. F. raised 1 foot.
Basket Scoops .	44,000	20,000	20,178	40,000
Bullock Mót . .	74,400	85,200	79,200	8,670
Picottah . . .	50,000	..	57,600	44,000
Ditto, Single .	..	12,860	33,000	..

The relative value to Government of irrigated and dry cultivation may be illustrated by the revenue returns of former years, of the fourteen Ryotwaree districts of the Madras Presidency already referred to. These comprise about 90,000 square miles, and it is calculated that 140 acres per square mile are occupied by houses, roads, &c., and that 200 acres remain waste; thus leaving about 300 acres per square mile under cultivation. Of this area, about one-twelfth is irrigated; thus giving approximately 2 million acres of irrigated and 25 million acres of dry land. The average revenue realized by Government from the former was $1\frac{1}{2}$ million sterling, against barely 2 millions from the latter, so that the irrigated land yields three times the revenue drawn from an equal surface of dry land.

As regards the gain to the cultivator from irrigated land, independently of the certainty of reaping the crop—it may be stated that the average intrinsic or market value of crops raised on irrigated land is 20 rupees per acre, against 6 rupees for the produce from un-irrigated land, or upwards of three-fold; so that the ryot is better able to pay 3 rupees per acre for the former, than 1 rupee for the latter.

The cultivation of un-irrigated land of course depends entirely on the local rainfall. On occasions of a scanty monsoon, the crop often falls short of the ryot's expectations, by from 16 to 20 per cent. When the rains entirely fail, the crop is altogether lost; and it may safely be stated that the aggregate of the remissions of revenue that thus become inevitable in the case of un-irrigated land would have more than sufficed to provide reservoirs of water, by means of which great loss of life, as well as loss of revenue, would have been prevented.

The amount of profit realized by the cultivator from an acre of irrigated land depends, however, entirely on the nature of the crop; sugar-cane may be instanced as the most profitable. If watered by tank or river water, sugar-cane will yield 2,300 seers of molasses per acre (a seer is equal to 2 lbs. English). Taking the sale price at 1 anna ($1\frac{1}{2}d.$) per seer, or $\frac{3}{4}d.$ per lb., this quantity would yield a gross return of 145 rupees per acre. Deducting the cost of cultivation, reaping, &c., say 53 rupees, there remains a gross

profit of 92 rupees, and after the further deduction of land rent, water rate, and taxes, say 30 rupees, the ryot still realizes a net profit of 62 rupees.

The great superiority of river and tank water for irrigation purposes, as compared with well and spring water, may here be adverted to, as an additional argument in favour of the formation of river and tank reservoirs. The Author has ascertained, from actual observation, as well as from the experience of practical authorities, that sugar-cane, watered from tanks and rivers, yields a much heavier crop than land watered from wells and springs, and the molasses produced from the former realizes double the price of the latter. As regards rice, it may be estimated, that each acre watered with river water yields 950 seers of paddy. Allowing 22 seers per rupee as the selling price (somewhat more than a halfpenny a pound) the crop will realize 45 rupees, and deducting 10 rupees as the cost of labour, and 15 rupees for the assessment, there still remains a net profit of 20 rupees to the ryot. On the other hand, a rice crop watered from wells or springs, would only yield about 418 seers of paddy, realizing a gross return of 19 rupees, and leaving, after the deduction of 12 rupees, a net profit of 7 rupees to the ryot.

Although the system of irrigation which obtains in Southern India is, on the whole, good and simple, yet great improvements could be effected, especially in the masonry works connected with the canals and channels. For instance, good sluices for letting off the water into the fields might at a small outlay be substituted for the present inefficient ones, whereby the supply would be better regulated, and the prodigal waste that now takes place would be prevented. The Author would also strongly advocate the repair of all the old tanks and channels.

It is true that many of these works are of small capacity; but they would suffice to supply the wells in the vicinity during the hot season, and thus meet the wants of the villagers and their cattle, as well as enable small patches of land to be irrigated, for the supply of forage. If the larger works were repaired, a great extent of land now lying waste, or under dry cultivation, could be irrigated and sown with valuable crops. One important indirect result would be that whereas, in former times, when the tanks were in good repair, trees were largely planted, and, as is always the case, vegetation attracted the moisture, and the monsoon could always be depended upon, now, since these works have fallen into decay, the vegetation has disappeared, and the monsoon has been precarious and insufficient. The Author is of opinion, that by means of a moderate outlay on irrigation works, the extent of irrigated land in India might in a few years be doubled.

In many localities, large profits might reasonably be expected to be realized, both from the construction of new works, and additions and improvements to existing ones. The great augmentation of revenue that has taken place in Southern India since 1838 is mainly due to the returns from irrigation works. In Tanjore, which was already a prosperous and well-irrigated district, a permanent increase of revenue of £20,000 has been obtained from an additional outlay of 40,000 rupees (£4,000); and the returns from the Godavery works, which were entirely new, have been at the rate of at least 33 per cent. on the outlay, although the water charge was very low. The vast extent of irrigation that is required, in order to obtain these important objects, may be judged of when it is considered that, calculating according to the usual proportions of 500 acres per square mile, out of the area of 800,000 square miles comprised within the British territories, 400 million acres ought to be brought under cultivation; and, as already stated, partially irrigated, in order to render the crop certain.

Statistics regarding the extent of land at present irrigated are meagre; but it may safely be stated, that not more than 4 million acres are watered by artificial works: and there appears to be no prospect, in spite of the large remunerative results obtained therefrom, of an outlay commensurate with the requirements of the country being incurred by Government, within any definite period. Irrigation being, however, of great importance, the question naturally arises, how this large outlay should be provided for. Numerous discussions have lately taken place, amongst those interested in the welfare of India, as to the relative advantages of carrying on works of public utility by means of private companies, and by Government establishments. Judging from personal experience and observation, the Author is of opinion, that, considering the vast area requiring to be provided with these works, the comparatively small extent of the Government establishments, and the large capital that will be needed, the object could best be attained through the agency of private companies. This view will, he thinks, be fully supported by a comparison of the operations of the Railway Companies, with those of Government in regard to irrigation works. The utmost sum that has been spent by the various governments and communities of India, on these primary and highly remunerative works, is about four millions sterling, during a long course of years; whereas, no less than about seventy millions sterling have within a few years been spent by private companies on railways, which are far less remunerative, and may, moreover, be called subsidiary works, dependent for their full development and success upon the prosperity of the people. It is true that objections have been raised, and possibly not without reason, against the management of private companies; but the defects that

exist are not inherent in their constitution, and might, the Author believes, be obviated under suitable arrangements.

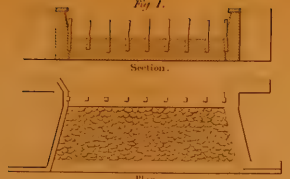
A company provided with ample capital and an efficient staff of engineers would be enabled to supply the want that has hitherto existed, of inducements to shareholders—beyond the moderate rate of interest guaranteed by Government—to press on the construction of public works, in the most rapid and efficient manner; and the realization of these advantages could not fail to attract capitalists. A feeling in favour of companies is beginning to spring up amongst the natives of India. They now perceive that undertakings such as public works afford a safer and more profitable investment for money, than the former system of sinking their savings in jewelry. This feeling will increase, as the remunerative results of irrigation works become more apparent.

In conclusion it is desired to refer to the construction of works, with a view to the combination of navigation and irrigation. Many Engineers hold that no good results can accrue from such a combination; but the Author is impressed with the advantage of having irrigation canals, where practicable, of sufficient section to be made navigable, thereby opening out a means of transport for the produce of the country at a cheap rate. This question may probably be dealt with in another Paper, at some future time.

The Paper is illustrated by a series of Diagrams, from which Plate 20 has been compiled.

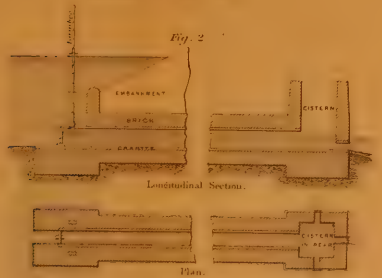
IRRIGATION IN INDIA.

Fig 1.



CALINGULAH, OR WASTE WEIR.

Fig. 2



NATIVE SLUICE.

Fig 3.

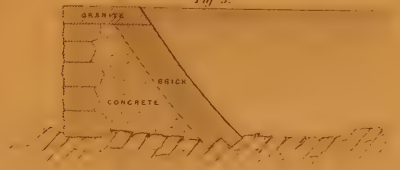
PROPOSED LAKE TO IRRIGATE 200,000 ACRES OF LAND.

Fig 4.

POSITION OF NATIVE ANNICUT.

SECTION IN FRONT OF ANNICUT.

Fig 5.



SECTION OF ANNICUT OR DAM.

Fig 6.

SLUICE ON CANAL BANK.

Fig 7.

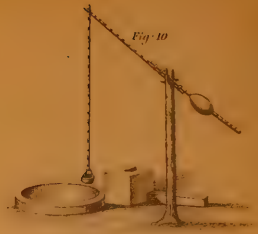
Fig 8.

CAUVERY PAUK TANK.

Fig 9

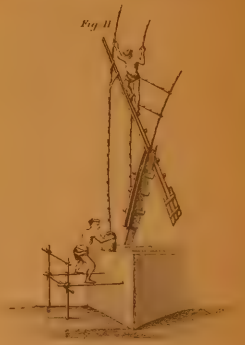
RAISING WATER BY BULLOCK MÔT.

Fig 10



RAISING WATER BY SINGLE PICOTTAH.

Fig 11



RAISING WATER BY DOUBLE PICOTTAH.

Fig 12.

RAISING WATER BY BASKET SCOOP.

No. 1,200.—"On the Benefits of Irrigation in India, and on the proper Construction of Irrigating Canals."[1] By THOMAS LOGIN, M. Inst. C.E.

PROBABLY in no country in the world is the necessity for the due adjustment of those natural influences which produce fertility and salubrity of climate more fully exemplified than in India. For instance, the cooling influence of the Himalayan Mountain range is essential to produce rain, from the warm and moist exhalations of the Bay of Bengal. But, owing to the occasional irregularities of the season, causing sometimes an excess, and at other times a deficiency of moisture, the skill of the Engineer is required to reduce these irregularities to a minimum. The Author has been engaged during the greater part of a quarter of a century on some of the most important irrigation works in Northern India, and an account of the most prominent features of the system may possibly be of interest.

Twenty-five years ago canals were supposed to be injurious to the climate, and Kurnaul was cited as an example of a military station having to be deserted owing to the unhealthiness caused by the Western Jumna Canal. Further experience has, however, shown, that defective drainage was the cause of the evil, for the swamps would have existed even had there been no canal. Hence it appears that the proper remedy is to drain these swamps, not into the river, but into the desert, for when the Jumna is in flood, it is on a higher level than the marshes. In this particular, not only should the swamps be drained, but more of the inundation water should in the first instance be turned into them, so as to warp them up, allowing this water after it had parted with most of its silt to flow into the desert. A few thousand cubic feet per second disposed of in this way, during the season when the Jumna is in flood, from April to September, would go far to improve the climate in that neighbourhood, while the land watered would be fertilized as in Egypt. An opinion now prevails, that irrigation, under a proper system, has a tendency to improve rather than to injure the climate; and accordingly the water has of late years been carried through military stations, instead of so as to avoid them.

It is difficult to estimate the political advantages of irrigation; but in a country like the Punjaub, almost wholly depending on artifi-

[1] The discussion upon this Paper was taken in conjunction with the preceding and succeeding communications and occupied portions of four evenings, but an abstract of the whole is given consecutively.

cial means for its fertility, and situated as it is on the borders of the north-west frontier, the advantage of having a contented, prosperous population, with rich fields of cultivation instead of extensive arid plains, cannot be overrated. The section of the Rechna Doab (Plate 21, Fig. 1) shows the general fall of the country, the spring water level, and the rainfall, as well as the extent of land under cultivation.

With respect to the financial aspect of the case, an inquiry into the direct revenue derived from the older canals and their actual cost shows that, at least in Northern India, immediate direct returns must not be looked for, although such canals are certain to be remunerative eventually. If, however, in addition to the water rent the increase of cultivation and the enhanced value of land be included, the canals even in this part of India must be considered highly remunerative.

The strong argument, however, in favour of canals is that they are calculated to prevent those awful visitations which from time to time sweep off hundreds of thousands by starvation; and if canals can be constructed at an outlay of somewhat less than one pound sterling per head of the population, and return a fair per centage for the outlay, these are additional reasons for constructing them without delay.

It may be added that the full development of irrigation would greatly enlarge the commerce between England and India; for irrigated land could support three times the present number of inhabitants of one of the most thickly populated portions of the globe. What is required, therefore, is a cheap mode of transport for the export of the surplus produce, when India will be able to compete with the world in supplying the necessaries of life as well as the luxuries.[1] It has been shown that, owing to the Ganges Canal, as many lives were probably saved in Bengal during 1865-66 as perished in Orissa in the same year; and during the following year, 1866-67, this canal repaid to the country more than its total cost, while it was the means of feeding little short of two and a half millions of people.[2]

The limits of this Paper will not admit of this subject, as to the utility of canals, being further pursued; and for the same

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[1] Upwards of 500 tons of wheat were shipped at Calcutta for England in October last. If there was cheap inland carriage, even now 10,000 tons might be shipped monthly, at £5 10s. a ton, or £10 a ton delivered in England.

[2] The Author finds, from the East Indian Railway Traffic returns, that in 1866 105,294 tons of grain were sent down country by this railway; and he is informed that a still larger quantity was conveyed by water carriage during 1865-6, thus confirming this argument. He has also ascertained that the actual discharge and revenue of the Ganges Canal in 1866-7 was about one-eighth below his estimates; but, as there was a still greater reduction on the original cost of the canal, the argument still holds good.

reason the interesting question of the abrading and transporting power of water in motion, can only be briefly adverted to. The Author believes, that the power of water to hold matter in suspension is directly as the velocity, and inversely as the depth. It is also suggested that water in motion rolls rather than slides, and that it is owing to this rotary motion, that water has the power to hold matter in suspension. Further, that with given velocities and defined depths, only a certain quantity of matter can be held in suspension, whatever may be the character of the bed and banks of the river or canal. If the velocity be increased, and the depth remain constant, scour will take place. If the velocity be decreased, and the depth is the same, there will be deposit. To such an extent is this the case, that at velocities sufficient with pure water to carry along large stones, a sandy or clay bed would be left undisturbed when once the water had got its proper load of silt, thereby indicating that in every case nature has adapted the channel to the circumstances. It has, however, to be borne in mind, that the real bed in many cases may be considerably below the apparent one after floods, and this must be provided for. Instances could be adduced in illustration of these views.

With reference to the best slopes for canals, and how the slopes are to be regulated, it is essential, in the first place, to ascertain what is the slope of the river, when not in flood, from which a supply is to be drawn off, under circumstances similar to those of the canal to be constructed—that is, as to depth and soil; and then to make a small allowance for the tortuous course of the natural river. By neglecting these indications of Nature, and acting on preconceived notions, errors are likely to arise. For example, much has been said about the excessive slope of the Ganges Canal; but the experience gained during the last five years has shown that, with velocities which with pure water would most certainly have scooped out the bed, there has been a steady silting up of the bed. (Plate 21, Fig. 2. Section of the Ganges Canal at Roorkee). This is owing to the nature of the water admitted into the canal, which from October to March is nearly pure; but as soon as the snow begins to melt in April, the water is highly loaded with silt. This is carried down the canal in the hot season, and is deposited over the canal bed, to be again picked up and carried forward in the cold season, when the water becomes more pure. The slope—that is the velocity, or in other words, the abrading and transporting power to be given—should be such that the deposits should be balanced by the abrasion. Experience on the Ganges Canal has shown that this requires a mean velocity of about $3\frac{3}{4}$ feet a second, with a surface slope a little less than 14 inches in the mile. This slope and velocity might be modified by admitting more water into the canal during the six hot weather months, when the slope

would have to be increased; or should the hot weather supply be diminished, the slope would have to be decreased. Under such circumstances, it is evident that vegetation cannot exist in the main canal where the bed is never constant; and in the minor channels the clearance of weeds is a matter of no great difficulty. The experience thus gained is also important in its bearing on the question of navigation. In the course of a previous discussion at this Institution, on the Employment of Steam Power on Canals,[1] it was proved that velocities exceeding $3\frac{1}{2}$ miles an hour caused a wave of translation which would injure the banks. Now, as it is requisite to have a mean velocity of $2\frac{1}{2}$ miles an hour for the Ganges Canal, it follows that, in forcing a boat up against the stream only $3\frac{1}{2}$ miles an hour, a speed of only 1 mile an hour could be attained, and that any attempt at quicker velocities would injure the banks; so that, irrespective of the loss of power in stemming a stream running at $2\frac{1}{2}$ miles an hour, the banks could not stand if there was quick navigation. Hence it would appear, that an almost still-water canal is required for navigation, in addition to the present canal, which however may be used for down-country traffic.

With reference to the mode of regulating the slope of canals, it is proposed to refer to some suggestions on the construction of canal falls. One of the greatest problems for the canal Engineer is the best method of dealing with the excessive slope of the country through which an artificial river has to flow. In nature this is provided for as follows:—First, by waterfalls, which abound in all hilly countries. Secondly, by barriers of rock, stretching like weirs across the channel of the river, also met with among the hills. Thirdly, by rapids formed of boulders that have been carried down the river, and thus create what may be called temporary weirs or barriers. And lastly, where only clay or sand exists, Nature, by making the course of the stream tortuous, adds to the length of the river, thus practically reducing the slope, and, to a minor extent, the flow is also retarded by the sudden bends in the river, which tend to check the velocity and to increase the depth.

The last plan appears to have been almost invariably adopted by Engineers in former times; and in the present day it is still to be seen in Egypt. In India, also, several examples of the kind are to be found; and one of the largest and best-paying canals in Upper India—the Western Jumna Canal—is constructed on this principle.

When surveying the Rechna Doab, the Author found indications of a like nature, with masonry escapes and sluices, but in no case did he discover any falls. Near Sealkote, Ali Murdan Khan, by adopting this tortuous, or rather zig-zag course along the top of a

[1] *Vide* Minutes of Proceedings Inst. C. E., vol. xxvi. p. 19.

ridge, was able in a few miles to bring the canal from the high ground of the Bhangar into the low lands of the Khadur. The fall of the country was so great, that any attempt at a straight line, or even to follow the course of the small 'nullahs' on each side would certainly have led to a retrogression of levels. The best proof of the success of the measures then taken is to be found in the fact, that the remains still exist of the extensive gardens of Sodrah, which were irrigated by the water of this canal.

It does not appear who was the first to introduce falls on canals in India. But the subject can only have been recently appreciated, as Lieutenant (now Colonel Sir) Proby T. Cautley had to build masonry falls to the Eastern Jumna Canal after it was opened. The experience then gained led to the adoption of the Ogee form of fall (though several others were suggested) for the Ganges Canal.

The change recommended by the Author while the canal works were in progress, was to lower the flooring of the fall, so as to form a cistern to receive the descending water.[1] (Plate 20, Figs. 4 and 5, Zig-zag Falls.) A French Engineer also recommended to Sir Proby (then Major) Cautley, a series of broad steps; and in 1862-3 this was partially carried out by the Author on all the falls in the first division of the Ganges Canal, by securing a framework of timber, 5 feet in height, above the crown of the Ogee, instead of trusting to sleepers, which were constantly giving way. By this arrangement the water is held up to about the level originally intended by the projector; and it is a remarkable fact that, though there is a perpendicular fall of 5 feet or more on the crown of the Ogee, no injury has as yet been done to the brickwork at the point where the water impinges. Probably this is owing to the water which passes through the open spaces of the timber framework forming a cushion for the descending water.

Where the deepening of the canal bed was excessive, owing to the increased velocity of the stream, prior to 1862, and the next set of falls was $11\frac{1}{2}$ miles lower down the canal, back water could not be held on the flooring of the Mahmoodpoor falls. The brickwork here being inferior could not withstand the violent action it was exposed to, and hence the serious accidents to this work in 1862. But by throwing a submerged weir, $3\frac{1}{2}$ feet high, across the chambers of the falls, a cistern was formed to receive the descending water, and the violent action was at once overcome. For the last five years, therefore, since these arrangements have been carried out, the canal bed has been gradually silting up, and little or no serious injury has resulted to the works, except to the Jowlee falls, the circumstances of which are similar to those of the Mahmoodpoor falls at one time. It is proper that these

[1] *Vide* Proceedings of Royal Scottish Society of Arts, March, 1857.

facts should be known, before other descriptions of falls are considered, as those on the Ogee principle have been so generally condemned. Sir Proby T. Cautley in adopting this plan, in preference to others, feared the concussion and the tremor that might be caused to works resting on quick-sands, which would probably loosen some of the bricks, and it is possible that this has happened in cases where the floorings rest on arches.

The plan for overcoming the excessive slope of the country on the Barree Doab Canal is chiefly by perpendicular falls, the water being received into a cistern. Rapids have likewise been used, where boulder stones were plentiful. In Madras perpendicular falls are also employed, but instead of the water falling into a cistern, it impinges on a flooring of ashlar work. As the slope of the deltas in Madras is comparatively little, falls are not so necessary, and as good building stone can be obtained at a moderate cost, a simpler description of fall is sufficient.

A system of under sluices has been suggested by Colonel Fyfe. This was thought of for the Ganges Canal, but it was considered that nothing but cast-iron sluices could stand, and twenty-five years ago this was deemed impracticable, as there was not a smith in the country who could weld together two pieces of English iron. Mr. Parker has proposed to contract the water-way at the falls, so as to preserve a parallelism between the surface of the water and the bed, which has the great recommendation of cheapness.

In the present day, the engineer has to avoid both injury to the land and to the climate, and instead of copying Nature, by making the course of an artificial river tortuous, and permitting marshes to exist, an artificial river should be so designed that the least possible area of land may be injured, and the climate improved rather than rendered more unhealthy. The last of the four natural methods of operation previously adverted to must, therefore, be discarded, and some other plan adopted, the study of natural provisions being still kept in view, as forming the best guide.

The first of the four cases mentioned relate to water-falls, but these only exist where hard rocks predominate. The third example, that of rapids, is found in all the rivers which drain the southern face of the Himalayas, which has already undergone the action of water. These rapids are not permanent, but year after year the boulders of which they consist are rolled forward, grinding and abrading each other, till they ultimately become sand or mud. The action of the water over them is also excessive, which is overcome by lengthened slopes; consequently this plan can only be adopted where boulders can be procured in large quantities and at little cost. Hence it appears that, under most circumstances, recourse must be had to the second mode of overcoming excessive slopes; namely, barriers, or, as they are technically termed, "weirs."

Belts of hard rock have been thrown up at certain distances across the course of some rivers in Southern India, which hold up the surface of the water at intervals with deep reaches between; and so deep are the reaches, and so slow the stream, that in some cases it is intended to make use of them for navigation, passing the barriers by locks. It is found, however, that above each barrier there is deep water, where except during floods the surface of the water, comparatively speaking, is nearly horizontal, though when the river is at its highest, these barriers, or rapids, sometimes almost disappear, being only observable by a slight 'swirl' on the surface over the site of the obstruction, as in the case of the Madras anicuts. This is found to be the case with rapids on the rivers in Northern India; and it is well known that it is quite possible to ford the Ganges in the dry season on an elephant, at the head of a rapid, but quite impossible to do so below one, owing to the great depth of water. In short the bed of the river is in no case parallel to the surface of the water, but in almost every instance slopes upwards from the foot of one rapid to the head of the one immediately below. Again, if these rapids, or fords, be examined, it will be found that they are never situated where the channel is contracted; and instead of crossing the stream at right angles, they are generally oblique to it, and on other occasions curve downwards to the stream. It is evident that Nature adopts this peculiarity, on purpose to extend the length of the rapid, and thus reduce the action. In England, from the time that water has been used as a motive power, mill dams and weirs are found to be situated in the broadest reaches of the rivers, and generally oblique to their course.

It is remarkable that where weirs are thrown across the bed of a river, they do not appear to raise the bed to any great extent on the up stream side; and instances have been known where it was difficult to raise laden boats sunk above weirs, but no sooner did a flood pass down, than the boat was lifted out of the deep water, and carried over the weir—thus showing an action on the bed of the up stream side to a considerable depth. With examples like these, it is evidently impossible to attempt to hold up the bed of an artificial river by bars or bridge-floorings, and any endeavour to do so only causes a disturbance in the flow of the stream. On the Ganges Canal, when first opened, and until sleepers were put in the grooves above the falls, deep holes were scooped out of the bed, on the up stream side. At the first fall, at Raneepoor, this occurred to a dangerous extent, as at one point the hole was upwards of 20 feet deep.

In nature the slope of the surface of a river is never constant, but varying according to the volume discharged. It is always greatest during floods, and this holds good in the plains, as well as among

the hills. In dry weather the stream never keeps the centre channel, but changes from side to side, thus adding still more to the length and reducing the slope. It has been supposed that stiff clay will prevent abrasion of the bed; but this appears to be an error, for the stiffest clay will be cut through in time, if the velocity of the current be too great. In Robison's "Mechanical Philosophy" it is stated[1] "that a velocity of 3 inches per second at the bottom will just begin to work upon fine clay fit for pottery, and however firm and compact it may be it will tear it up. . . . A velocity of 6 inches will lift fine sand; 8 inches will lift sand as coarse as linseed; 12 inches will sweep along fine gravel; 24 inches will roll along rounded pebbles an inch diameter; and it requires 3 feet per second at the bottom to sweep along shivery angular stones of the size of an egg." In practice, however, it is found to be different, and deposits take place with velocities far in excess of this. The Author has found in Upper India, that three times the velocity is required to hold in suspension the earthy matter admitted into canals from turbid rivers that would be sufficient to disturb and roll along the same description of matter over the bed if the water was pure. A clay bed is no doubt a great advantage, as it prevents absorption, and on this account it should not be cut through if possible.

It is now proposed to describe a new description of fall, recommended by the Author for the Rechna Irrigation Works, which appears to meet most of the difficulties alluded to. Before doing so, however, a Table is given (p. 479) showing, approximately, the sections and slopes best adapted for irrigation canals and water courses in Northern India.

The experience gained on the Ganges Canal tends to prove that both the depth and the slope may be increased. A Committee lately recommended a reduction of about 1 inch per mile, less than that intended by Sir Proby Cautley; thus showing that the flow of water is retarded considerably, by having a load of earthy matter to transport.

With the quantity of silt carried down by the canals in Northern India, if 10 per cent. be added to the slope given in the Table, probably a close approximation to the actual state of matters will be arrived at, with a corresponding reduction of the widths and increase to the depths of the channel. From the Table it will be seen that the best slope for a canal in Upper India, discharging 5,000 feet per second, is about $13\frac{3}{4}$ inches, or 1·15 foot in the mile. Taking the Ganges Canal as an example, it is found that the flooring of the regulator at the head is 133 feet above the canal bed at the end of the 50th mile, and 217 feet at the end of the 100th mile. Therefore the general slope of the country in

[1] Vol. ii. p. 465.

TABLE showing approximately the SECTIONS and SLOPES probably best adapted for IRRIGATION CANALS and WATER COURSES for NORTHERN INDIA.

Cubic Feet of Discharge per Second.	Calculated Sections.					Proposed Sections.			Side Slopes of Channels.	Remarks.
	V. Mean Velocity in Feet per Second.	H. Hydraulic Mean Depth.	Breadth of Channel at Bottom.	Depth of Water with full Supply.	Slope of Surface of Water in Inches per Mile.	Breadth in Feet at Bottom.	Depth in Feet with Full Supply.	Slope of Surface of Water in Inches per Mile with Full Supply.		
cubic feet.	feet.	feet.	feet.	feet.	inches.					
50	2	2	$2\frac{1}{2}$	4	15	2	$4\frac{1}{2}$	$16\frac{1}{2}$	1 to 1	Calculated on Beardmore's Formula.
100	$2\frac{1}{4}$	$2\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{3}{4}$	$14\frac{1}{2}$	4	$5\frac{1}{4}$	16	1 to 1	$\frac{11\sqrt{H \times S}}{12} = V.$
250	$2\frac{1}{2}$	$3\frac{1}{3}$	15	5	$13\frac{1}{2}$	$13\frac{1}{2}$	$5\frac{1}{2}$	$14\frac{5}{6}$	1 to 1	Where H = Hydraulic depth in feet.
500	$2\frac{3}{4}$	$4\frac{1}{4}$	$27\frac{1}{2}$	$5\frac{1}{2}$	13	25	6	$14\frac{1}{3}$	1 to 1	„ S = Fall in feet of Surface of Water per mile.
1,000	3	5	50	6	13	45	$6\frac{2}{3}$	$14\frac{1}{3}$	1 to 1	„ V = Mean Velocity in feet per second.
2,000	$3\frac{1}{4}$	6	$77\frac{1}{2}$	7	13	70	$7\frac{3}{4}$	$14\frac{1}{3}$	$1\frac{1}{2}$ to 1	In no case should the mean velocity exceed 4 feet per second, $3\frac{3}{4}$ probably being the safe limit, and not less than $2\frac{3}{4}$ feet for the main channels. Keeping in mind that the greater the velocity the cheaper the section in deep digging.
3,000	$3\frac{1}{2}$	7	95	8	$12\frac{3}{4}$	85	$8\frac{4}{5}$	14	$1\frac{1}{2}$ to 1	
4,000	$3\frac{1}{2}$	$7\frac{1}{2}$	$121\frac{1}{2}$	$8\frac{1}{2}$	$12\frac{3}{4}$	110	$9\frac{1}{3}$	14	$1\frac{1}{2}$ to 1	
5,000	$3\frac{2}{3}$	$7\frac{2}{3}$	$147\frac{1}{2}$	$8\frac{1}{2}$	$12\frac{1}{2}$	130	$9\frac{1}{3}$	$13\frac{3}{4}$	$1\frac{1}{2}$ to 1	
6,000	$3\frac{3}{4}$	8	170	$8\frac{3}{4}$	$12\frac{1}{2}$	150	$9\frac{2}{3}$	$13\frac{3}{4}$	$1\frac{1}{2}$ to 1	

the first 50 miles is 2·66 feet per mile, and in the second 50 miles 1·68 foot per mile. In the first 50 miles, therefore, the excessive fall would be 75½ feet, and in the second 50 miles 26½ feet. In the first instance, with steps of only 5 feet each, fifteen falls would be required, or on an average one fall at every 3⅓ miles; or in other words, no road bridges would probably be required along these first 50 miles, except for one or two high roads. Again, along the next 50 miles only ten road bridges and five falls would be necessary; or, in all, twenty falls and ten bridges. Along the first 100 miles of the Ganges Canal there are three regulating bridges, thirty road bridges, and eleven falls with bridges,—in all forty-four bridges. Leaving the regulating bridges out of consideration (as probably necessary under any circumstances), still there would be a saving of ten bridges in the 100 miles.

Supposing the proposed 'zig-zag' falls to cost only one-half less than those on the Ganges Canal, and double the price of road bridges, or say £4,000 each, there would be

Thirty road bridges at £2,000 each =	£60,000
Eleven falls . . at £8,000 each =	£88,000
Total . . .	£148,000
Against ten road bridges at £2,000 each =	£20,000
And twenty zig-zag falls at £4,000 each =	£80,000
	£100,000
Difference . . .	£48,000
Total	£148,000

or a saving of nearly one-third in masonry works for bridges and falls along the first 100 miles; or, in other words, the cost would be considerably under, rather than over, the present plan.

Again, by making use of falls of 5 feet instead of 8 feet or 9 feet, the saving in depth of digging would average less by one-half the difference of height of fall; and as by this 'zig-zag' fall system the breadth at the falls requires little or no increase on the present plan a considerable saving in earthwork would be effected.

The next question to be determined is, whether the falls are likely to stand the action of the water. It is proposed that the length of the lip should be so extended that only 10 cubic feet a second shall pass over each foot, which with a full supply will require a height of water of about 2 feet. Now it has been already shown, that no injury has as yet occurred to the Ganges Canal with two and a half times the volume descending an equal height on brickwork. It is apprehended that there can be little danger where there is a cistern to receive the water; and it is also evident that, as this height of fall increases, the volume of water

diminishes, so that there can be little doubt of the work standing, even if only brickwork be used.

With reference to the utility of the falls, it has been shown that, on the up-stream side of a weir, there is an action on the bed, and examples have been given in proof of this. Above all the falls on the Ganges Canal the bed is found to be 1 foot or more deeper than it was originally excavated, though the water is held up 5 feet by a framework of timber.[1] The water in the canal, with a full supply, may, therefore, be considered to be as deep immediately above the weir as at any point higher up; so that when the whole volume is passing down, the depth will be $9\frac{1}{3}$ feet throughout.

Should the falls be only $3\frac{1}{3}$ miles apart there would be $3\frac{1}{2}$ feet of water at the down-stream side of every fall, and $7\frac{1}{3}$ feet on the up-stream side; or the canal could on any occasion be closed, and yet contain one half of a full supply in such reaches as did not require repairs. Thus, if necessary, the injured works might be repaired, and both above and below such points navigation and partial irrigation might be maintained during the time that the canal was closed.

Any injurious effect to the climate would be avoided, as it would not be necessary to lay dry to the action of a tropical sun, such an extensive area as the whole canal bed, even for a few weeks, which at present no doubt has a bad effect. The great advantage, however, of this description of fall is due to the extended lip. Owing to the great length of the lip, not only is the action on any point reduced, but the variation in the head of water is also reduced to a small limit. Having the head of the distribution channels just above one of these zig-zag falls, would practically secure the command of a constant supply for them. Even supposing no attempts were made to regulate the discharge down the distributing channels, by having this extended lip to the falls, the variation would be within reasonable limits, as the following example will show. Suppose the distributing channel to be only able to discharge 100 cubic feet, with a full supply of 5,000 cubic feet a second passing down the canal. By the Table, the section of the distributing channel would be $4\frac{1}{2}$ feet broad at the bottom, with slopes of 1 to 1, and a depth of $4\frac{3}{4}$ feet. To reduce the supply in the canal from 5,000 to 4,000 cubic feet a second, where the surface of the water is always parallel to the bed, the depression

[1] This frame-work of timber has irregular open spaces, through which some water passes, and probably when the volume of water is very small, this prevents any silting up on their up-stream side. A system of iron sluices might be arranged, to produce a similar effect, but to be self-acting, so as to open with an increased supply, and thus reduce to a certain extent the variation of the head of water passing over the lip, while at the same time affording the means of laying the bed dry when necessary.

of the surface would be nearly $1\frac{1}{4}$ foot, with a corresponding fall in the distributing channel, which would reduce its discharge from 40 to 50 per cent. Where the fall with a zig-zag lip was used, the depression would only be $3\frac{1}{2}$ inches, which would reduce the discharge in the distributing channel about 13 per cent.; while the supply down the distributing channel would only be reduced to one half, when only 1,000 cubic feet a second were passing over the weir. By this example it will be seen that the variation can be reduced within practicable limits, to admit of the discharge being measured.

In October, 1867, when the Ganges Canal was laid dry, a careful examination was made of the nine falls along the first 60 miles of the canal. The result of this inspection tended to confirm the views previously expressed as to slopes.

Plate 21 Fig. 9 will assist to show at what excessive slopes the canal was running, prior to the time when the Author held up the water above all the falls in November, 1862. The expedient for protecting the falls, recommended in November, 1861, (No. 1) was intended to make use of such materials as were available for the purpose. No. 2, shows what was carried out a year later, under pressure of trying circumstances, such as appeared to justify anticipation of official sanction; and the Author ventures to submit, that this simple framework has mainly contributed to the saving of the Ganges Canal from destruction. It represents the arrangements for holding back water on the flooring of the Mahmoodpoor falls, which were officially sanctioned in January, 1863, and then carried out. This work was found in October, 1867, to be still in perfect order. No. 3, shows the change that was introduced in August, 1867, by removing the framework of timber that had been erected five years previously, in order to hold up the water above the falls, and substituting a brick wall protected by planking. In several parts the brick on edge was, however, being washed out at the point of greatest impact. With this exception the canal bed and the works appeared to be in a most satisfactory state, which cannot but be a matter of congratulation to all well wishers of India, who know that the lives of millions of human beings depend on this canal. Six years ago the Author stood almost alone in maintaining the opinion, that the Ganges Canal needed only some protective work, and did not require the radical alterations then proposed. The Author will only add the expression of his firm conviction, that the works may be placed out of danger, by the judicious use of wood and iron, at a less cost than if stone be employed, without depriving the country of the benefits of irrigation beyond a short time.

This Paper is illustrated by a series of Diagrams, from which Plate 21 has been compiled.

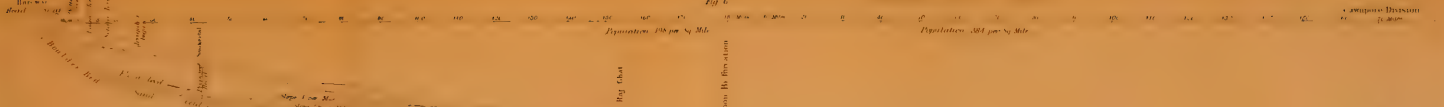


Fig 6
Rise per Mile
Slope 1 in 1 Mile
Slope 1 in 2 per Mile
Slope 1 in 4 per Mile
Big Ghat
Manoora Bifurcation
Slope 1 in 2 per Mile
Slope 1 in 4 per Mile
Slope 1 in 1 Mile

No. 1,204.—"Irrigation in Spain: chiefly in reference to the construction of the Henares and the Esla Canals in that Country."[1] By George Higgin, M. Inst. C.E.

The subject of the irrigation of land by canals and dams is one that has lately begun to excite a good deal of interest in England, chiefly in connection with India, where their construction has at last been seen to be of vital importance for the well-being of the people; nor is it less important in Spain to the Spaniards, for it may safely be said, that almost the entire future well-being of that country depends upon it.

Irrigation in Spain is one of peculiar interest for the Engineer, as in that country the effects of centuries of experience can be studied. Its earliest, and indeed almost all its irrigation works were constructed about A.D. 800 or A.D. 900, when Spain was under the dominion of the enlightened and enterprising Moors; and the laws and customs which have grown up about them are interesting and curious. Perhaps the system of irrigation, and the whole administration of the waters, in Valencia and Murcia are as perfect as can well be, and the results are very surprising. Unfortunately, a full description of these works, as they ought to be described, would far exceed the limits of this Paper, and, therefore, they will only be cursorily noticed, with a view to collect such data as may assist in the description of the new canals now in course of construction by the Iberian Irrigation Company.

Of all the countries in the world, there is perhaps none that so much requires irrigation as Spain, nor one which so gratefully repays the labour expended upon it, by rich and valuable results. The climate of the south and east of Spain is suitable for the production of crops of almost all kinds: productions of the torrid and the temperate zones here grow together. In the gardens of Murcia and Valencia may be seen wheat, barley, corn, maize, the orange, the lemon, the date-palm, the olive, the citron, the peach, the pear, the apple, rice, pepper. In Malaga and Seville, in addition to these are the sugar-cane, the cotton-plant, the prickly-pear, and in sheltered spots the plantain, which is seldom found out of the tropics. The soil of most of the river plains is a rich alluvial deposit, from 3 feet to 10 feet in depth. Nothing is wanting but water; and this may frequently be seen a few yards off running to

[1] The discussion upon this Paper was taken in conjunction with the two preceding ones, and occupied portions of four evenings, but an abstract of the whole is given consecutively.

the sea, useless, and unproductive. A few Tables of comparative rainfall and temperature have been prepared, which will bring this point more forcibly before the mind than any figures can do. Table No. 1 contains the mean monthly rainfall over a period of four years in Madrid, Seville, Valencia, Valladolid, Alicante, Granada, and Zaragoza. Table No. 2 shows the mean monthly temperature at the same places.

TABLE 1.—MEAN MONTHLY RAINFALL taken for an Average of Four Years.

MONTHS.	Madrid.	Seville.	Valencia.	Valladolid.	Alicante.	Granada.	Zaragoza.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.
January .	1·09	5·54	·95	·57	·52	2·40	1·22
February .	·89	4·11	1·75	1·76	1·31	2·26	1·21
March . .	·58	·91	1·56	1·53	1·97	2·36	·86
April . .	·39	1·21	·29	·86	·19	3·69	1·03
May . .	1·70	2·29	2·23	3·06	1·83	5·90	1·83
June . .	1·01	·29	·82	2·36	·69	3·37	1·53
July . .	·71	..	1·26	·31	1·31	1·29	2·02
August .	·82	·18	·67	·68	1·45	·11	1·23
September.	·10	·57	·46	·18	·22	·08	·82
October .	1·56	1·89	2·04	3·36	1·41	1·45	1·19
November.	1·80	2·78	2·64	4·63	2·34	7·11	1·80
December .	1·33	2·74	1·21	1·56	·34	3·40	2·30
Total . .	11·98	22·51	15·88	20·86	13·58	33·42	17·03

TABLE 2.—MEAN MONTHLY TEMPERATURE in various parts of SPAIN taken from an Average of Four Years.

MONTHS.	Madrid.	Seville.	Valencia.	Valladolid.	Alicante.
	Faht.	Faht.	Faht.	Faht.	Faht.
January. . .	39·7	54·1	48·9	34·3	52·0
February . .	41·6	57·7	51·4	44·6	53·6
March . . .	45·6	59·5	53·2	49·4	54·5
April . . .	55·7	67·4	63·3	51·8	61·9
May . . .	57·5	71·0	67·8	49·6	64·7
June . . .	67·2	80·9	73·7	68·3	71·4
July. . . .	74·1	86·2	82·4	77·9	76·6
August . . .	77·1	91·7	84·2	74·1	79·1
September . .	75·4	89·2	81·8	66·5	77·7
October. . .	61·8	79·0	71·8	50·5	70·7
November . .	54·5	71·0	65·6	44·9	64·4
December . .	45·5	62·9	54·7	37·6	57·7

In order to show, more effectually, however, the exceptionally dry climate of Spain, Tables Nos. 3, 4, and 5, have been prepared. Table No. 3 shows the comparative mean temperature of Italy and Spain during the seven irrigating months. Table No. 4 contains the comparative mean annual rainfall of Italy, Algeria, and Spain.

TABLE 3.—COMPARATIVE TABLE of Mean TEMPERATURE during the Seven Irrigating Months, in Italy and Spain.

MONTHS.	Lombardy.			Piedmont.	Spain.				
	Milan.	Pavia.	Brescia.	General Average.	Madrid.	Seville.	Valencia.	Valladolid.	Alicante.
	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.
March . .	44·6	47·3	48·4	45·09	45·6	59·5	53·2	49·4	54·5
April . .	54·8	55·9	57·0	51·95	55·7	67·4	63·3	51·8	61·9
May . .	64·0	65·3	64·4	61·49	57·5	71·0	67·8	49·6	64·7
June . .	70·5	74·1	71·0	74·84	67·2	80·9	73·7	68·3	71·4
July . .	74·8	78·1	75·0	74·63	74·1	86·2	82·4	77·9	76·6
August .	71·4	75·4	74·1	71·53	77·1	91·7	84·2	74·1	79·1
September.	66·4	66·9	67·1	62·91	75·4	89·2	81·8	66·5	77·7

TABLE 4.—MEAN Annual RAINFALL in ITALY, ALGIERS, and SPAIN.

		Inches.
Italy . .	Lombardy . .	38·
	Piedmont . . .	37·
Algiers . .	Algiers . . .	27·
	Bône	25·
	Oran	14·5
Spain . .	Granada . . .	33·42
	Seville . . .	22·51
	Valladolid. . .	20·86
	Zaragoza . . .	17·03
	Valencia . . .	15·88
	Alicante . . .	13·58
	Madrid . . .	11·98

For that of Italy the rainfall given by Colonel Baird Smith for Lombardy and Piedmont has been taken. This is stated to be an average of ten years. The rainfall for Algiers has been taken from M. Aymard's treatise on Irrigation. It is an average of four years from 1858 to 1861. The rainfall for Spain has been taken from the records of the Royal Observatories, also for an average of the same years. It will be seen that, with the exception of Oran, Spain is by far the driest country. While Piedmont has a fall of 37 inches, Lombardy 38 inches, Algiers 27 inches, and Bône 25 inches, Spain has only an average of 17 inches; and in two cases, that of Madrid and Alicante, the mean annual fall is only 12 inches and 13½ inches respectively. Oran, with a mean rainfall of 14½ inches, is the only place that at all approaches these in dryness. The most extraordinary result, however, is that shown in Table No. 5: in this the mean rainfall and temperature during the seven irrigating months from March to September, and the mean maximum temperature during June, July, and August, of Lombardy, Piedmont, and Spain, shows that, while Piedmont has a

mean temperature of 63°, and a mean maximum of 85°, with a rainfall of 29 inches, Seville, with a mean temperature of 78° and a maximum of 111°, has only a rainfall of 5½ inches. Madrid, with a mean temperature of 65°, and a maximum of 98° has a rainfall of only 5 inches. Alicante and Valladolid, though a little better than Seville and Madrid, are far inferior in rainfall, and superior in heat to either Lombardy or Piedmont. The vital necessity of irrigation is very apparent.

TABLE 5.—COMPARATIVE MEAN AND MAXIMUM TEMPERATURE AND MEAN RAINFALL OF ITALY AND SPAIN, during the Seven Irrigating Months from March to September.

		Mean Rainfall.	Mean Temperature.	Maximum Temperature.
		Inches.	Faht.	Faht.
Piedmont . .	General average	29·	63·20	85·32
Lombardy . .	Milan . . .	22·	63·20	85·90
	Pavia . . .	22·	66·10	88·00
	Brescia . . .	22·	65·30	86·40
Spain . . .	Madrid . . .	5·31	64·69	98·00
	Alicante . .	7·66	69·41	94·00
	Valladolid . .	8·98	62·51	90·00
	Seville . . .	5·45	77·98	111·00

It is extraordinary that with such a climate, and with the well-known results of irrigation, the Spaniards should have allowed a single drop of water to run to waste. In reality, little has yet been done to irrigate the country, and what exists is chiefly the work of the Moors. The principal rivers in Spain are, as is well known, the Tagus, the Duero, the Guadalquiver, the Guadiana, and the Ebro. With the exception of the land irrigated at Aranjuez by the Tagus, and the comparatively small irrigations from the Ebro, in the Rioja, Aragon and Catalonia, all the waters of these fine rivers run idle to the sea, in many cases through magnificent plains, which require nothing but water to render them rivals of Valencia and Murcia. In addition to these well-known rivers, there are many minor streams, such as the Esla and the Henares, which could be applied to irrigation; and even if the rivers were used up, Spain is a country which is most suitable for the construction of large reservoirs for this purpose.

The most ancient and valuable irrigation works in Spain are those from the Turia and Jucar in Valencia; from the river Segura in Murcia; and from the rivers Darro and Genil in Granada. These were all the works of the Moors, and have been very little extended since their time. The irrigation works of Valencia are supposed to have been executed A.D. 800. When Don Jaime I. of Aragon conquered Valencia from the Moors in A.D. 1238, he found the irriga-

tion works in full operation, and the following year, by a royal decree, he divided the lands amongst his followers, and granted them the free use of the waters, as they had been used in the times of the Saracens. When the same king conquered Murcia in A.D. 1275, he found irrigation also in full force, and as he had before done in Valencia, so here, too, he divided the lands and granted the use of the waters, "according as was anciently accustomed and established by the Saracens." The works at Granada were also constructed by the Moors. These came into the power of the Spaniards at a later period, for it was not till A.D. 1492 that Ferdinand and Isabella finally expelled the Moors from that place. The irrigations of Lorca and Elche were likewise initiated by the Moors. The great dams, however, formed for the storage of water, belong to a later date; those of Puentes and Valdeinfierno, in Lorca, having been built during the reign of Charles III. A.D. 1785 to 1791. It is to this enterprising and enlightened monarch that Spain owes almost all the comparatively modern works. He it was who took up and carried to conclusion the magnificent Imperial Canal of Aragon,—begun by Charles V., in the year 1528, but unfinished and abandoned for more than two centuries,—which irrigates upwards of 50,000 acres of ground on the right bank of the Ebro above Saragossa. Thanks to him also the Canal of Tauste, which irrigates over 19,000 acres of land on the opposite bank of the same river was supplied with water. He projected the Canal of Tamarite, which, taking the waters of the rivers Cinca and Esera, was to irrigate the fertile plains of the Litera. He also began the works of the Urgel Canal, which, having been since abandoned and commenced again many times, have now been completed within the last few years by a Spanish Company with a heavy subvention from the State. The projects of the Esla and the Henares Canals, likewise date from his time.

The principal large irrigated areas in Spain are as follows:

	Acres.
Castellon, from the River Mijares	22,373
Valencia, from the River Turia	25,935
Valencia, from the River Jucar	30,875
Gandia, from Alcoy and Bernisa	7,145
Murcia, from the Segura	25,915
Orihuela, from the Segura	50,318
Elche and Cieza, from the Segura	10,370
Granada, from Darro and Genil	46,930
Lorca, from Guadalantin	27,170
Elche, from River Vinalapo	29,640
Almansa, from a dam	3,458
Alicante, from a dam	9,139
Nijar, from a dam	about 9,000
Catalonia, right B. of Llobregat	6,651
Imperial Canal of Aragon, from the Ebro	50,066
Royal Canal of Tauste, from the Ebro	19,284
English acres	374,269

If to these be added, for irrigations in the Rioja and in other parts of the Ebro, irrigations from the Ter in Catalonia, and from other rivers in Aragon and Catalonia, about 60,000 acres, the total will be 434,269 acres, or, say, 680 square miles, as representing the principal irrigation works in Spain. According to the published Government returns, the total amount of irrigated ground in Spain is 4,439 square miles. Deducting the 680 square miles mentioned above, this would leave an area of 3,759 square miles as being due to irrigations from water-wheels, small canals not taken notice of here, tanks, &c. This, however, is manifestly excessive, as no such amount of irrigation exists. The total area of Spain, according to the Government returns, is 190,947 square miles. Of this amount, 46 per cent. is returned as being under cultivation. Even admitting that 4,439 square miles of this is irrigated, as stated in the returns, this would only give a percentage on the total cultivated land of $4\frac{1}{3}$ per cent. The effect of irrigation upon the land in Spain is marvellous. The value of the land rises ten, fifteen, or twenty times. While the rate of population in all Spain is only 81 to the square mile, in the irrigated garden of Murcia there are 1681 inhabitants to the square mile, and in Orihuela 767 inhabitants per square mile. Were the portion of Spain now under cultivation populated at the rate of the irrigated portion of Orihuela, the total would be 78,576,082.

From certified copies of sales made at Castellon during the year 1859, it appears that the average price of irrigated ground was £140 per acre, the average price of dry ground in the same neighbourhood being £10. On the same authority it appears that the average price of an acre of irrigated ground in the garden of Murcia was £500, the price of dry ground in the same neighbourhood being £25 to £30. In the immediate neighbourhood of Valencia land sells for prices varying from £200 to even £400 per acre. The proportionate value of irrigated and unirrigated ground obtains not only in the old irrigated districts, but all over Spain. In the royal property of San Fernando, about 7 miles or 8 miles from Madrid, which was irrigated by Ferdinand VII., irrigated land lets for £5 per acre. Exactly the same class of ground, but dry, in the immediate vicinity can be bought in fee for the same sum. In the valley of the Esla, in the province of Leon, where a small portion of land is irrigated on the left bank of the Esla River, the average value is £120 per acre; while the dry ground in the same valley sells for £8 or £10. As a rule, all over Spain, good land in the valleys unirrigated may be bought at an average price of from £6 to £10, irrigated ground from £80 to £120 per acre.

In proportion to the value of the ground is the value of the water. Colonel Baird Smith gives the value of a cubic foot of water per second in Piedmont at £16 per annum, and in Lombardy

at about £15 per annum. In most of the old systems of Spanish irrigation, the water is attached to the land, and is sold with it; and the value of the water cannot be ascertained. In two cases, however, there is an exception, viz., at Elche and Lorca. In these places the water is sold every morning by public auction. M. Aymard gives the average value of a litre of water per second per annum as £78 12*s.* 10*d.* This amount may appear high; it is, however, strict reality. The water is annually sold at that rate. The exceptionally high price of this water is due, however, to its great scarcity. But perhaps the fair average value of a cubic foot of water per second in Spain, may be taken to be that fixed by the Government for the Henares Canal, viz., £375 per annum, which was not considered a high price.

The Author will now proceed to describe the Henares and the Esla Canals. In the spring of 1863 a company was formed in London, for the purpose of constructing irrigation canals in Spain; and the concessions of two canals were purchased, one being to irrigate the valley of the Henares, in the provinces of Madrid and Guadalajara; the other, to irrigate the valley of the Esla, in the provinces of Leon and Zamora. The Engineers appointed by the company were Mr. Bateman (M. Inst. C.E.) and the Author, who was at that time resident in Madrid.

The projects for irrigating the Henares and the Esla Valleys were of very old date. They were first started in the reign of Charles III.,—the most useful king that Spain has ever had; but they never came to be facts until 1859, when the actual concessions were granted. Perhaps of the two canals, that of the Henares is the more valuable, inasmuch as it is within a short distance of Madrid, and the railway from Saragossa to Madrid runs through the valley from end to end. It contains also within its zone two large towns: Guadalajara, which is the capital of the province of that name, and Alcalá, once the seat of learning in Spain, and even now a considerable town. The distance from Alcalá to Madrid by railway is 35 kilometres—say 20 miles; by road it is somewhat less.

The River Henares takes its rise amongst the mountains of the Somo Sierra, and after running for a length of 96 miles, falls into the Jarama near the royal property of San Fernando, not far from Madrid. Its course is extremely steep, and the current very rapid. The total fall of the river, from the weir of the new canal to Alcalá, a distance of 36 miles, is 407 feet, giving a mean fall per mile of 11·3 feet. As a consequence, the line of the new canal offers an immense mill-power, which, from its proximity to Madrid, will be of great value. After making due allowance for the loss of water for irrigation, filtration, and evaporation, there will be a total nominal horse power, for nine months of the year, of 3,630 HP.,

and for the remaining three months of 1,450 HP., divided over twenty falls, of which the most powerful are, as a matter of course, near the commencement of the canal. The geological formation of the valley is the upper tertiary. It forms a portion of a vast hollow basin, the edges of which are cretacean; and its situation would lead one to expect, that large quantities of water might be met with by Artesian wells of inconsiderable depth. The land is in general very good, more especially in the lower portions. About Alcalá it is as good as any land in Spain. At present the only crops grown are cereals, as from the absence of irrigation it is impossible to produce any other crop. The whole of the valley is under cultivation, and for Spain it is thickly populated. The total length of the new canal is 46½ kilometres, say 28 miles. It takes its water from the river at a point 16 miles above Guadalajara, just below the junction of the Sorbe and Henares, and ends at Alcalá. The total area of ground embraced by the canal is 12,400 hectares, say 30,628 acres. Of this amount, however, some portion cannot be irrigated, and after deducting this, and that due to roads, streams, towns, &c., there remain about 11,000 hectares, say 27,170 acres of ground capable of irrigation. For this purpose, the volume of water conceded by Government is 5 cubic metres per second, say 175 cubic feet for nine months, from October to June inclusive, and 3 cubic metres per second, or 105 cubic feet, for the remaining three months. From accurate measurements made near the new weir since the commencement of the works, it appears that during the months of July, August, and September, the average quantity of water carried by the river is 210 cubic feet per second, the lowest point which it has touched being 140 cubic feet per second. During the remainder of the year it carries an average of 300 or 400 cubic feet per second. It is subject, however, to enormous floods, which come down with great rapidity; and in designing the new weir it was necessary to provide for the floods. Several came down during the progress of these works, some of which were estimated to be carrying 8,000 cubic feet per second. The weir, it is calculated, will discharge 20,000 cubic feet per second, which is more than in all likelihood it can ever be called upon to do. Old inhabitants, however, show marks which would indicate a discharge of at least 12,000 feet per second. Several mills are situated on the river, which, it is evident, will be almost entirely deprived of water during the dry season by the new canal; but the Government does not allow these interests to interfere with those of irrigation.

The preliminary operations were commenced on the 1st January, 1863; and in July of the same year the undertaking was formally inaugurated by the Director-General of Public Works. The most difficult portion of the canal is comprised in the first 10 kilometres. Immediately after leaving the river, the canal runs into

a heavy rock cutting, 2,500 metres long, and with an average depth of 16 feet. At 2,780 metres from its commencement, the canal reached the most difficult portion of its course, a high limestone cliff, which overhangs the river. In the original plans it had been proposed to carry the canal in a covered way along the *débris* in front of this cliff, but a slight examination showed that it would be impossible to do this with safety; and it was at once decided to tunnel the cliff. This tunnel has a total length of 2,900 metres, say 3,171 yards, and at its exit a further length of 300 metres of deep cutting in gravel had to be carried between walls. At the 9th kilometre the canal crosses the Madrid and Saragossa Railway, and at the 10th kilometre, a wide torrent bed, known in the country as an "Arroyo," had to be crossed. This and the railway crossing were the binding points in this section of the canal; and it was with reference to them that the actual height of the new weir was fixed.

The site chosen for the new weir was the only one where a good foundation could be expected. Plate 22, Fig. 2, shows a cross section on the axis of the weir. The bed of the river was composed of compact clay rock, very impermeable, mixed with strata of excessively hard conglomerate. The crest of the weir was at an average of 6 metres above the river bed; but on the right bank where the river channel ran, it was considerably deeper. Fig. 3 shows a cross section of the weir as constructed. The front wall, to a height of 2·50 metres below the crest of the weir, was built of rubble in hydraulic mortar, the foundation being benched into the rock, which was blasted for the purpose. The main body of the weir was of hydraulic concrete, the apron being faced with cut stone blocks, 2 feet deep and 1 foot thick, every fifth row being a bond 3 feet deep and 1 foot thick. The toe of the weir was formed by two stones, 3 feet 6 inches deep and 1 foot thick, let 3 feet into the solid rock—and from this sprang the apron. From the top of the rubble wall to the crest, the weir was entirely of cut stone. Three courses 2 feet high, and one course 2 feet 4 inches high, carried it up to the due level. The lower course of stones were immense blocks, measuring 5 feet on the bed, 2 feet high, and never less than 3 feet 3 inches on the face. They were cut with a check, upon which the succeeding course rested, and V joints were cut in every face, and were run in with pure cement after the stone was in its place. The back portion of these stones was filled with cut stone, carefully jointed to fit exactly into the places; and the whole when completed, formed a perfectly impermeable mass of cut stone. For the purpose of guarding against filtration, a continuous line of cut stone was let into the rock in the centre of the concrete. These stones were 2 feet deep, one half being sunk in the rock and one half rising up

into the concrete. They were all bedded in pure cement, and were cut with V joints also run in with cement. Fig. 1 shows the form of the weir on plan. It is composed of two curves, one of 121 metres radius, and the smaller one of 60½ metres radius. The abutments were founded upon the rock in a similar manner to the weir, and were built of large blocks of rock-faced ashlar, in courses 50 centimetres high.

The water for the canal is drawn off by five sluices. These are set in masonry-arches of the same class of work as the abutments. At the entrance of the canal there are three sluices, for the purpose of scouring out any deposits which may accumulate in front of the gates. The cill of these sluices is 1 foot lower than those of the canal sluices, these latter being 5 feet under the crest of the weir. Immediately inside the head sluices, and forming a portion of the head-works, an overflow weir, 12 metres wide, is built, in order to provide for the discharge of any waters which a sudden flood might admit into the canal during the absence of the guard. This is necessary, as floods have been known to come down so quickly in this river as to carry away women who were washing on the banks. The building of this weir was intrusted to a firm of Spanish contractors, who did their work fairly and honestly. Not a single case occurred in which they endeavoured to introduce any bad material or workmanship. But the incessant care of the Resident Engineer, Mr. Higginson, as well of his assistant Mr. Armytage, was necessary to prevent mistakes taking place, from want of knowledge on the part of the contractors of this kind of work. The stone, which was an exceedingly hard limestone of a pale buff tint, was brought from the top of the hill on the left bank of the river. The actual distance from the work was only 3 kilometres; but as the height was great, and there was no road, a distance of 7 kilometres of transport was allowed in arranging the prices of stonework.

The river, at the time of the commencement of the work, ran in two channels; one close to the left bank which was shallow, and carried very little water; the other, which was the principal channel, ran close to the right bank. The work was begun on the left bank, and carried forward until close upon the deep channel, a gap being left in the weir near the left side of the river. When the work arrived at the deep channel, the river was turned, by throwing a bank across it at some distance above the weir, and the foundations of the right bank were then put in. The weir is 120 metres long, say 130 yards, between the abutments. Its total cost has been, including all the headworks and the waste weir, £17,343. The total cubical contents of the weir are as follows:—

Abutment, left bank	401 cubic yards.
Abutment, right bank, including regulating weir .	582 ,,
Weir	5,957 ,,
Making a total of . . .	6,940 ,,

The mean price of each cubic yard has therefore been a little under £2 10*s.*

The prices paid to the contractors were as follows:—

	£.	*s.*	*d.*
Excavation in bed of river, in gravel, including all expenses of pumping and diversion of river, per cubic yard . .	0	7	2
Ditto, ditto, in rock	0	15	2
Ashlar of all kinds, except the crown of weir . . .	2	16	0
Ashlar in the crown of the weir	5	14	0
Hydraulic concrete	1	0	10

The lime used was that made at Zumaya, in the Basque provinces, which was found by experiment to be the best of all the hydraulic limes in Spain. Its cost, delivered on the works, was 20 rials per quintal, Spanish, say 4*s.* 7*d.* per cwt., English. When fresh and used pure, it sets quickly with great heat. It was mixed in the proportion of 2 of sand to 1 of lime. The hydraulic concrete was in the proportion of 5 of lime, 9 of sand, and 22 of gravel or broken stone. It set very hard, made an excellent job, and withstood successfully the tremendous floods that sometimes swept over it during the construction of the work. One flood which came down when the weir was unfinished, tried it severely. The water rose 4 feet over the crest of the finished portion, completely filling up the gap, and pouring with great force on the exposed concrete hearting of the unfinished end. This flood was estimated to have a volume of more than 9,000 cubic feet per second. Not a single stone was displaced. The weir was completed finally in June, 1867. It is to all appearance perfectly water-tight, and seems likely to stand as long as the weirs of the enterprising Moors.

During the time occupied in the construction of the weir, the works of the long tunnel had been vigorously pushed forward. The contract for this portion of the work was originally given to a Spaniard, but this was dissolved, and a new contract was entered into with Messrs. Roberts and O'Shea, of Madrid, who completed it entirely to the satisfaction of the Engineers. The construction of the tunnel offered no engineering difficulties. About one-half of it was in a stiff, tenacious clay, the remainder being in limestone rock. It was found necessary to line the whole with brick, as the rock, though hard when first cut, crumbled under exposure to air and water. Fig. 6 shows the general position of about one-half the tunnel. At 240 metres from the commencement, it crossed a torrent bed, the level of the top of the

tunnel being slightly under the bed of the torrent. Two points of attack were thus obtained running in almost on the level. At 900 metres farther on, the same thing occurred; and at 4,580 metres the tunnel ran into the side of the hill, and a portion. 220 metres in length, was able to be constructed by open excavation. In addition to these natural faces, seven galleries were run in from the side of the cliff, so that there were in all twenty-two faces; and the work could consequently be quickly pushed on. In most cases, a shaft was sunk from the top to meet the gallery, for the purpose of preserving the line of the tunnel. In the case of the two galleries, however, shown on Fig. 6 and marked A and B, this was not done, it being determined to run these in by triangulation. For this purpose a base line was selected on the opposite side of the river, and being carefully measured, the distances by triangulation were obtained from the centres of the two towers fixed on the top of the cliff over the line of the tunnel. The direction of the galleries was then given from the measured base, and a stone, with an iron centre let into it, was sunk at the entrance of each gallery, and the distance of these points being again found by another measurement, the distance between this and the first calculated distance gave the length of the gallery to the centre of the tunnel. When this point was reached, the measured angle upon the base was set off, and the work was commenced upon all four faces. About 70 or 80 metres were driven in this way, the tunnel being taken out for its full width. As, however, a long distance had to be driven before meeting the next faces, and it was considered inadvisable to drive a heading, on account of the small size of the tunnel and consequent extra cost, it was thought that the risk of going on upon the calculated lines was too great, as a slight error, either in the measured base or in the angles, would have created a large error in the lines of the work. A couple of shafts were accordingly sunk at the points marked C and D, when, to the satisfaction of all concerned, the new lines dropped from the surface were found to coincide almost exactly with those given by the triangulation.

The section of the tunnel and the different thicknesses of arching are shown in Figs. 7, 8, and 9. The bricks used were made in the valley, and after a little trouble, they were obtained of good quality. The bricks generally made in Spain are of an inferior quality and very thin. It is not possible to obtain them thick, in consequence of the difficulty of getting firewood to burn them. The size adopted for the Henares tunnel was 11 inches by $5\frac{3}{4}$ inches by $1\frac{3}{4}$ inch. The width of this brick makes it awkward to handle, and English bricklayers do not like them. The Spaniards, however, do not seem to object to them. The Spanish brick contains 110 cubic inches, being 10 inches more than the English

one. They were delivered on the works at 2*l.* a thousand. The whole of the brickwork was set in hydraulic mortar. As it was found, however, that the pure lime and sand set too quickly, the custom of the country was followed, and a percentage of white lime was mixed with the hydraulic, the proportion being 1 part of hydraulic, 1 part of white lime, and 4 parts of sand. This mortar was longer in setting than the pure mortar, and gave much better results. It cannot be used where the work is liable to be immediately covered with water; in the tunnel this was not the case. The prices paid for the tunnel were as follow:—

	£.	*s.*	*d.*
Section Fig. 1, in clay, three rings in arch, and two in invert, per lineal yard	14	2	3
Section Fig. 2, in earth, two rings in arch, and two in invert .	12	6	5
Section Fig. 3, in rock, two rings in arch, and one in invert .	13	5	5

The clear diameter of the tunnel inside is 3·40 metres, and its height 2·22 metres. It was finished on the 30th May, 1866, a year before the weir. Air shafts were left at three of the faces where the tunnel came out near the surface, and four of the galleries were bricked in, so that easy admission might be had to the tunnel at any time (Figs. 10, 11, and 12). The remainder of the galleries and shafts were filled in.

The only other works of importance on this canal are an aqueduct over the Arroyo Tejada at the entrance of the tunnel; the bridge under the railway, and the bridge over the Arroyo Majanar.

The difficulties presented by the bridge under the railway were simply those caused by the work having to be carried on without disturbing the passage of the trains. This was done by shifting the line and building one-half of the abutments at a time. The railway was carried on wrought-iron girders sent out from England. In consequence of the little headway which could be obtained over the Torrent Majanar, it became necessary either to carry the canal over by a tube or under by a syphon. It was resolved to adopt the former plan, and the canal is carried over in a wrought-iron tube of 20 metres, say 65·6 feet, span (Fig. 13). This tube was constructed by Messrs. Rankin, of Liverpool. It was put together by native workmen acting under an English foreman. The men employed were Basques, who in a short time learnt to rivet, and turned out excellent workmen. They never put in less than one hundred rivets a day, and this under an August sun, with the thermometer up to 120° or 130°, the iron being so hot that it was almost impossible to touch it with the hand. The joint of this tube with the masonry was made as follows:—A strip of 7 lb. lead was bolted securely to the end flange. The lower end of this lead was fixed in a channel cut in the stone, and run with a mixture of pitch, tar, and sand. The sides were completed in the same way. By this means,

the tube can change slightly by contraction or expansion without risk of leakage. In addition to this joint, the tube rests on a flannel pillow soaked in tallow, and the side flange was packed with oakum and tallow. There was thus a double joint. This tube was the last thing done. It was immediately filled with water to the depth of 5 feet, and has since been kept full. It is perfectly tight, both at the joints with the masonry and in other parts. With a load of 93 tons of water, it sank $\frac{1}{4}$ inch in the centre. At the side of this tube are three sluices for discharging the canal if necessary.

The remaining works on this canal are not of much importance, the only considerable one being an aqueduct over the Arroyo Dueñas, consisting of two arches 20 feet span each, with a height from the bed of the 'Arroyo' to the coping of the canal of 26 feet. The approach to this bridge is rather heavy, the bank containing 32,000 cubic yards. A good deal of difficulty is experienced in Spain in works of this class, from the exceptional character of the streams and waterways. The rainfall in most parts of Spain is irregular, and large quantities fall within a few hours. Thus, in the month of May, showers will frequently fall in Madrid almost tropical in volume, to be succeeded by three or four months of nearly perfect dryness. From the denuded nature of the country, and the absence of any species of herbage, the rain runs off with great rapidity: every depression becomes for the time-being a torrent, and it is necessary to provide for their discharge. As they all bring down large quantities of gravel, it is not possible to pass them into the canal; and for the same reason it is dangerous to pass them under the canal, unless a free discharge can be made for them at the lower side. In cases where this was difficult, and the nature of the ground permitted it, these streams are carried over the canal by means of small iron tubes (Plate 22, Fig. 13). In the Esla valley, where the extreme flatness of the ground, and the absence of any defined watercourses, render it difficult to pass the streams under, the greater portion of them are passed over the canal in this manner. In many cases the country roads become torrent-beds in time of rain, and provision has to be made for both kinds of passes. These were variously treated, according to circumstances. In some instances headway was obtained by altering the canal section to a wide, shallow bed; in others, the canal itself was passed under by means of a masonry syphon. In all the works of the canal economy was sought, as far as was compatible with good workmanship. The greater portion of the ordinary roads were passed over by small timber bridges. Where the roads were of more importance, brick bridges were constructed. The timber bridges cost on an average, all things included, £120 each. The brick bridges cost £200 each. A considerable extra cost in these bridges was caused by the necessity of using twisted batters for the

approaches and exit of the water. All works under the water-line were built in hydraulic mortar; above that line, in white mortar. All arches, both above and below the water-line, were turned in cement. At all the mill-falls sluice-gates are provided on the main line of the canal, the fall having a slope of 2 to 1; it is paved with cut stone 9 inches deep, laid in hydraulic mortar on a bed of concrete 18 inches thick. The water is measured out to the mills over an iron weir similar to the system adopted for the measuring of the irrigation water. One hundred litres per second, falling one metre, is taken as an effective horse-power. This is equivalent to about 44,000 lbs. lifted 1 foot high in one minute. A horse-power on this canal lets for £10 per annum, the lessee erecting all his own works.

The average prices paid for the smaller works were as follow:—

	Per cubic Yard. £.	s.	d.
Ordinary brickwork	1	9	9
Brickwork in arches	2	0	0
Ordinary rubble	0	19	3
Ashlar	2	15	0
Hydraulic concrete	0	17	8

The usual price for earth excavation was 10*d.* per cubic metre = 7½*d.* per cubic yard.

All the excavations were executed in the usual method of the country; that is, carried in small baskets, which hold a little more than a cubic foot of earth. When the material had to be transported any distance it was carried on donkeys; wheelbarrows are scarcely known. It was found to be cheaper to allow the people to work in their own way than to attempt to teach them. The banks where the canal ran above the ground were made of well-selected earth, rammed in layers about 6 inches thick, and each layer thoroughly soaked with water. Some of these banks were very expensive, in consequence of the distance which had to be traversed to find good earth. Where they were made from side cutting they cost 20*d.* per cubic metre = 15*d.* per cubic yard. The greatest expense generally was the water.

The labourers employed chiefly belonged to the province; but there were others from Galicia, Navarre, and Aragon. Their usual wages were eight rials, say 20*d.*, per day, and they are exceedingly dear at the price, for they do not perform more than about one-third or one-half the work of an English navvy. The stonecutters in most cases were Basques. Their average wages were 16 rials, say 3*s.* 2*d.*, per day. They are good workmen. The bricklayers were mostly from Aragon and Catalonia. Their wages were about 18 rials, say 3*s.* 9*d.*, per day. They were pretty good, laying their bricks well but slowly; the Catalans were the best. The

masons were nearly all from Galicia. They gained 2*s.* 11*d.* per day. They build fair rubble, but do not understand the management of the face work. The best face work they do is a kind of mosaic not built in courses.

The sections adopted for the first division of the canal are shown in Figs. 4 and 5. The inside and outside slopes are 1½ to 1, and the banks are 1·80 metre, say 6 feet, wide on the top. The depth of water in the first few divisions is 1·50 metre, say 5 feet, and the velocity adopted was 70 centimetres, say 2 feet 4 inches per second. This is rather high, but it is a matter of importance in Spain to avoid exposing the water in wide shallow channels; as with a less velocity weeds grow freely. Many of the old canals and watercourses of Spain have a mean velocity of 90 centimetres, or 3 feet per second.

One of the most interesting questions in the construction of an irrigation canal is the acreage which can be irrigated with a certain disposable quantity of water. Opinions vary much upon this point. In the garden of Valencia the quantity of water supplied to the land differs in each canal. This is easily understood, as they were constructed at different epochs; those first made having greater privileges than the later ones. The Canal de Moncade, which was specially reserved to the Crown by James I. of Aragon, when he conquered Valencia in the year 1238, had special privileges, and has a larger dotation of water than the others. The Canals de Rovella and Rascaña are applied specially to supply the town with water and to irrigate the immediate gardens. With these exceptions the mean dotation of the remaining five canals is ·86 of a litre per second per hectare. The dotation of the 12,500 hectares irrigated by the River Jucar is on an average 2 litres per second per hectare. The greater portion of this land is under rice cultivation, which requires, during the season of the crop, to be constantly kept under water. In Spain the usual dotation for rice crops is considered to be 2·25 litres per second per hectare.

The total area irrigated in Gandia is 2,893 hectares, and the dotation is 2,398 litres per second, equal to ·80 litre per second per hectare. The total area of the gardens of Murcia and Orihuela is 30,863 hectares, and according to a measurement of the river made just above the weir by a commission appointed for the purpose in 1815, the volume of water was 23,000 litres. This gives a dotation of ·74 litre per second per hectare. The River Genil in Granada irrigates 6,900 hectares with 2,000 litres per second, giving ·29 litre per second per hectare. In Elche and Lorca the economy of water is carried to the greatest pitch. In Elche 12,500 hectares are irrigated with 820 litres per second, giving only ·068 litre per second per hectare. In Lorca 11,000 hectares are irrigated with 340 litres, giving only ·031

litre per second per hectare. In the latter case the annual value of a cubic foot of water per second is £2,202.

Mr. Ribera, the Engineer-in-Chief of the Isabel II. Canal, with whose waters it is proposed to irrigate a small extent of ground in the environs of Madrid, found from a series of experiments made during the years 1863 and 1864, that the quantity of water consumed in the irrigation of a nursery garden was ·36 litre per second per hectare, and for a market garden ·47 litre per second. In both these cases the water was supplied without stint according to the demands of the cultivator, care only being taken to measure the actual quantity of water given. Mr. Ribera afterwards decided upon giving a dotation of not less than ·75 litre per second per hectare, without any apparent reason, inasmuch as the former measure included losses by filtration and by evaporation to a large extent. Probably he expects that a more intense cultivation will be practised in the immediate neighbourhood of Madrid than would be the case elsewhere. The usual amount said to be necessary for one irrigation of a hectare in Valencia is 700 cubic metres. This quantity is probably exaggerated, or has been arrived at by imperfect measurements, such as those made by a mixed Commission of engineers, architects, and citizens in Murcia, in the year 1818; when they found that to irrigate one hectare required 2,462 cubic metres of water, and afterwards, proceeding on this basis to calculate the quantity of water the river ought to carry to satisfy the irrigation of their plain, found it would be nearly three times that which the river carried, and which had sufficed for the wants of the landholders for upwards of nine hundred years. The Author found, from experiments made near Madrid, that the quantity of water employed by cultivators, in cases where they had no necessity to stint themselves, was from 400 to 500 cubic metres per hectare. Now allowing 450 cubic metres per hectare, and adding 15 per cent. for loss by evaporation and filtration, it will be found that $\frac{1}{2}$ a litre per second, would irrigate one hectare every twelve days. This is quite sufficient for the cultivation of almost any crop except rice, and taking into account the fact that, in a large valley, such as the Henares, there must always be a great variety of crops, many of which would only require irrigation every twenty or thirty days, it is evident that $\frac{1}{2}$ a litre per second is a good dotation for a canal. Putting this measure into terms of a cubic foot English, it would result in a dotation of 1 cubic foot per second to every 140 acres. The quantity allowed in the Indian irrigation canals varies, it is believed, from 120 to 200 acres per cubic foot per second. The quantity of water actually conceded to the Henares and the Esla Canals is, for the latter, 6,000 litres per second; for the Henares it is 5,000 litres from October to June inclusive, and 3,000 litres for the remaining three months, July, August, and September. Since the

Esla Canal irrigates 13,000 hectares, this will allow a dotation of ·46 litre per second per hectare; and for the 11,000 hectares of the Henares, ·455 litre per second during nine months, and ·273 litre per second for the remaining three months.

Supposing that a volume of 450 cubic metres were given to each hectare in each irrigation, it would be possible to irrigate the whole of the Esla valley once every 11·3 days; the Henares once every 11·4 days during nine months of the year, and once every 19 days during the remaining three months.

The canon fixed by government for the Henares Canal, in accordance with contracts previously made with the various towns to be irrigated, is Rvon. 344 = £3 11*s.* 8*d.* per hectare, on the condition that the concessionnaire gives twelve irrigations of 700 cubic metres each, or Rvon. 28·66 = 5*s.* 11½*d.* for each irrigation of a similar volume. This is equivalent to 18 rials = 3*s.* 9*d.* per irrigation of 450 cubic metres, which is the price the company are now selling at. The canon fixed for the Esla Canal is 19·4 rials = 4*s.* 0½*d.* per hectare per irrigation, each irrigation being 650 cubic metres. With an irrigation of 450 cubic metres, this will be 2*s.* 9½*d.* The lower price of the water in the Esla valley is in consequence of the less expensive character of the works, those of the Henares costing double those of the Esla.

The price of water in Spain varies considerably. The old Moorish irrigation works having been granted to the followers of the conquerors, pay nothing, except a small annual tax necessary for the repairs and conservation of the works. In Alicante the price of one irrigation of 460 cubic metres varies from 10 rials up to 250 = 2*s.* 1*d.* to 52*s.* 1*d.*, according to the scarcity of water and the dryness of the season. In Lorca one irrigation of 500 cubic metres costs on an average 120 rials = 25*s.* In Almansa one irrigation costs 12 rials = 2*s.* 6*d.* per hectare. In Granada each irrigation costs from 20 to 40 rials = 4*s.* 2*d.* to 8*s.* 4*d.* per hectare, but the proprietors also pay for all repairs. In Catalonia the Canal del Llobregat charges on an average 132 rials = 27*s.* 6*d.* per hectare per annum. The Canal of Urgel, lately completed, charges 229 rials = 47*s.* 8*d.* per hectare. In Malaga and Marseilles the same price is charged. The mean price paid per annum per hectare on the Esla and the Henares Canals will be respectively 48*s.* 9*d.* for the first, and 71*s.* 8*d.* for the latter.

It will be impossible within the limits of this Paper to enter into the interesting question, as to the best method of measuring the water to be supplied to the landowners: the most that can be done is to allude briefly to some of the modes adopted. In the old Moorish works no actual measure of water was attempted in the sense at present understood. The quantity of water in the river or canal was divided proportionally over the lands irrigated: if the

river brought more water, each canal received more; if less, less. Some of their systems for dividing the water were sufficiently ingenious. The system adopted at Elche was that used by the Moors before their expulsion from the country. The quantity of water in the river is divided into twelve equal portions, each of these portions being called a "hilo de agua," the "hilo" being the twelfth portion of the river running for twenty-four hours. These are sold every morning by public auction, and the prices they fetch are almost incredible. The system by which the proper proportion of water is taken off for each canal is shown on Plate 23, figs. 5 and 6, which has been copied from M. Aymard's treatise. The water is conducted along a level masonry channel with a very slow velocity, till it falls over a drop. At a distance of 1 metre farther on it falls over another drop. In the intermediate space between these two drops is fixed a little pier, which divides the breadth of the channel into two portions, the smaller one being more or less that belonging to the canal for which the water has to be taken. The point of this pier consists of a moveable vane, terminating in a sharp edge, which, when it is in a straight line with the pier, almost touches the first drop. It is evident that by moving this arm, the sheet of water flowing over the drop can be divided within certain limits with considerable accuracy. After every sale the person in charge of the distribution goes round and fixes these arms, allowing to each channel the proportion of water which corresponds to it; and thus they remain for twenty-four hours, until the next sale takes place, and a new division becomes necessary.

The method of dividing the waters in Lorca is shown on Plate 23, figs. 2, 3, and 4. In this case the space through which the water passes is divided into the number of proportional parts or "hilos," supposed to be in the river. At the left-hand side is the opening through which flows the water which it is proposed to take off for the secondary channel. Both these openings are capable of being closed by small vertical bars of wood, which drop into a channel cut into the masonry below, and are held at the top by two iron bars. There are exactly as many of these wooden bars as there are "hilos" in the stream; if, for instance, the main stream carries twenty-four "hilos," and it is necessary to take ten off for the secondary channel, fourteen of the wooden bars are taken out of the principal channel and ten out of the side one. It is manifest that as a measure of water this is open to many objections, but it is ingenious, and interesting when it is considered that it has been in use probably upwards of eight hundred years.

The principal objects to be sought in a module are, simplicity of arrangement of the different parts, freedom from friction or any similar deranging cause, constant discharge under varying heads, and, of course, an exact measure of quantity. It is of great im-

portance that there should be no concealed machinery, not only from its liability to derangement, but because there is then so much more liability to an alteration in the discharge, without its being noticed by the guard. It is also of importance to have, if possible, such a measure as can be easily inspected by the landholders, in order that each man may, if he pleases, satisfy himself that the proper quantity of water is flowing into his channel.

The Milanese module is perhaps the one best known. (Plate 23, figs. 7 and 8.) The principle of this module is that of discharging the water through a certain opening under a constant head. For this purpose a unit of measure was fixed on, called the "oncia magistrale," which is that quantity of water which flows freely under the sole influence of pressure through a rectangular opening having a uniform height of 7·86 English inches, a breadth of 4·12 English inches, and a constant head above the upper edge of the outlet of 3·93 English inches. The water is admitted from the main canal by a sluice into the first chamber, which, according to law, ought to have a length of at least 20 feet, in order to deaden the flow of the water. The floor of this chamber is inclined from the sluice up to the outlet, and in some cases a covering of planks, or slabs, called the "cielo morto," is placed across the chamber at the regulation height. It is the guard's duty to see that the water in this chamber does not rise above the height; and for this purpose he is charged with the key of the sluice. The outlet is cut in a slab of stone, edged frequently with iron. It is evident that if this aperture were cut in a thin plate, if the head of water were constant, and if it arrived at the aperture in a state of stillness, a result as nearly exact as possible could be obtained. In practice, however, it is not very accurate: the outlet given above being assumed as a unit, any number of "oncias" are supposed to be given by merely increasing the width of the opening by the required number of "oncias;" and it is supposed that this will give a simple multiple of the first unit. This is not, however, the case. By the addition to the width of the opening, the discharge increases more than a certain number of units: thus, an opening of the width of six "oncias" discharges much more than six separate openings of one "oncia" each. The water arrives also with too much velocity at the aperture, as the dimensions required to diminish it and the other points are never strictly observed; and the result is, that while the Milanese module possesses some of the elements required in a good module,—simplicity of arrangement and facility for examination both by the guard and by the people interested in the irrigation,—it is erroneous in its construction, and does not give unvarying discharges.

On the Marseilles Canal, water is measured by being allowed to

fall into a tube which passes through the bottom of the water chamber. This tube being attached to a float, rises and falls with the water, and preserves the mouth of the tube at a fixed level below the surface. In practice this does not work well, as it is almost impossible to preserve free working of the tube in the bottom plate, and at the same time to avoid leakages. This plan, however, has suggested to Mr. Ribera the most ingenious module which has perhaps yet been devised. (Plate 23, fig. 1.) A chamber is constructed at one side of the canal, into which the water is admitted through a screen. In the floor of this chamber is fixed a wrought-iron plate, having in it a circular hole of a given diameter. Into this hole hangs a pendulum of parabolic form suspended by a float, the water escaping in the space left between the pendulum and the orifice. The dimensions of the pendulum being accurately calculated, it is evident that with the rise or fall of the water a greater or less opening is left for the discharge, which can therefore be kept constant under all heads. This module is entirely free from most of the objections that the others are open to. There is no friction of parts, no liability to derangement, and the discharge is made under one of the few conditions in which it is believed water can be accurately measured. The only objections to it are, the loss of head and the disturbance that might result from the deposit of mud on the floor of the chamber, in which case the orifice would assume a trumpet form. As most of the rivers in Spain bring down large quantities of mud in suspension, this objection might have some force.

Lieutenant Carrol, of the Royal Engineers, has lately taken out a patent for a new method of measuring water (Plate 23, fig. 9). In this case the velocity of the water acts upon a plate, an increase of velocity or weight of water closing the discharging orifice. It has been tried on the Ganges Canal, and is said to give good results. It is in fact a reproduction of Dr. Arnott's stove draught regulator applied to a current of water instead of air. The objections to this module are, first, considerable loss of head; secondly, necessity of concealing the machinery; and thirdly, liability to derangements in consequence of the friction on the different parts. This last objection is the most fatal.

The module adopted on the Henares and the Esla Canals cannot lay claim to novelty; but it is believed it will fulfil its purpose practically. The water is merely measured by being discharged over a knife-edged iron weir. Plate 23, figs. 10, 11, 12, and 13 show this module. The water is admitted from the main canal by a sluice working in the division wall B. After entering from the canal the water passes into the first chamber C, and from thence into the second chamber D, where the weir is fixed. The communication between the two chambers is made through narrow slits, and the water

arrives at the weir without any perceptible velocity, and perfectly still. The weirs vary from 1 metre to 2 metres in breadth, according to the quantity of water required to be passed over. On the wall of the outer chamber is fixed a scale, with its zero point at the level of the weir edge, and by means of this scale any person can satisfy himself that the proper dotation of water is flowing into the distribution channel. By managing the sluice the guard can regulate to a nicety the height of water to be passed over the weir. This module has several good points. The system of measurement is that which possesses the most fixed rules in hydraulics, and gives the most constant results; it is simple and almost incapable of derangement: it will serve equally well for turbid waters as for clear ones: it can take off the waters with the least possible loss of head, a most important point in canals such as the Esla, where the loss of a few feet of headway would prevent the irrigation of many thousand acres. The guard can see at a glance whether the proper amount of water is passing into the course, and the irrigators can satisfy themselves on the same point. The only reasonable objection to this module is that any sudden variation in the head of water in the canal will affect the discharge, which will continue to be greater or less than it ought to be according to circumstances, until the guard comes round again. This is undoubtedly true; and to meet this objection it was at one time proposed to use a moveable weir suspended from floats working inside the pillars, which would rise and fall with the water and preserve the crest of the weir at an invariable level below. (Plate 23, figs. 16, 17, and 18.) On reconsideration, however, it was determined not to put this in, as in most well-regulated canals there is never likely to be any perceptible variation in the head of water. There is generally a guard in charge of the head-works, whose special duty it is to see that a constant body of water is admitted into the canal. If the river is flooded, he must close the gates; if it diminishes, he must open them. The water taken off from the canal for the different watercourses is a fixed quantity, and that passed on to the lower portion is, therefore, likewise invariable. The only cause of a sudden change of head would be in the case of a sudden and heavy fall of rain; but to provide against this at every 2 or 3 kilometres, there is a waste weir which would immediately carry off the surplus waters; and even if a little more was discharged through the module for a short time, no inconvenience would result from this. On the whole, as a practical working module, that adopted for the Henares and the Esla Canals is probably as good as can be wished for. Experiments are now being made to ascertain the proper coefficient for these weirs under varying heads.

As regards the probable losses by filtration and evaporation, it is

difficult to arrive at any reliable calculation. Mr. Ribera estimates, from experiments made on the Isabel II. canal, that the total loss from both causes will be only 2 per cent. of the whole body of water carried. This appears low; but it must be borne in mind that the whole of this canal is to be lined with masonry. Nadault de Buffon gives the average percentage on canals as 15 per cent. of the total volume carried. He does not mention under what circumstances such a percentage may be expected. Now, it is quite evident that any estimate for filtration must be expressed in terms of the wetted border and depth or pressure of water, and no general rule can be arrived at that will apply to all kinds of canals. Experiments are being made on the Henares Canal to ascertain the loss by filtration in ordinary earth under varying depths, with a view to obtain more precise data. The evaporation in Madrid, according to the returns of the Royal Observatory for the year 1867, was as follows:

	Inches.
January	$1\frac{1}{2}$
February	2
March	3
April	$5\frac{1}{4}$
May	$6\frac{3}{4}$
June	$10\frac{1}{4}$
July	$13\frac{1}{2}$
August	11
September	6
October	$3\frac{3}{4}$
November	$1\frac{1}{2}$
December	$\frac{1}{2}$
Total	65

The total amount of water evaporated from the Henares Canal during the month of July would be 99,042 cubic metres, which would be equivalent to nearly $\frac{3}{4}$ per cent. on the total amount of water carried.

Another important point to the irrigation engineer is the principle to be followed in the distribution of the waters. Plate 22, Fig. 14, represents a portion of the valley of the Henares now under irrigation. The system of distribution is shown by the dotted lines. It is divided into portions of about 300 or 350 hectares, say 750 to 850 acres, each of these plots being served by one of the primary channels, taken off direct from the main canal. On this primary channel at its point of departure from the main canal is fixed one of the modules before described, and by this module the dotation of water necessary for that area of ground is measured. Thus, for 300 hectares the dotation would be $300 \times \cdot 45 = 135$ litres per second. In cases where the water is distributed by the Company

amongst a number of small proprietors, it is done in this way: the total amount of water is passed into each of the secondary channels, and irrigation begins on the plot at either end of the channel. By means of the Company's survey and register, the acreage of every plot in the valley is known; it is only necessary therefore to calculate the number of minutes or hours the stream must run to give a certain quantity of water, and give the distributor his book with the names of the proprietors in their order and the hours that each must have the water. After the stream has run for the time allotted to it, it is shut off and turned on to the next field; and so on until all the fields depending on that secondary channel are irrigated. The stream is then shut off that secondary channel and turned on to the next in turn; and so on until all are irrigated, and the first is commenced again. In some instances the larger proprietors have wished to take into their own hands the distribution of the water upon their estates; and in these cases the module shown on Plate 23, figs. 14 and 15 has been used. Its mode of working is as follows:—suppose the primary channel to be conveying 150 litres per second, and that one of the larger proprietors wishes for a dotation of 50 litres per second into his own channel. The water of the primary channel is passed into the chamber A, from whence it passes through divisions in the party-wall into B, where it arrives in a state of almost perfect stillness. This chamber has two openings—one which is a continuation of the main primary channel, and the other which leads to the secondary channel. These openings are provided with weirs of sheet iron, and over these the water discharges. It is only necessary to proportion the width of the weirs to the amount they have each to discharge, and as the head is the same for both, they will each discharge their proportionate parts. Thus, roughly speaking, in the case under consideration, the weir on the secondary channal would require to be one-half the width of that on the primary channel.

So much time has been occupied in describing the Henares Canal, that it will be impossible to enter into any detailed account of the Esla Canal. This, however, is scarcely necessary, as the general remarks made upon the Henares would in most cases apply to the Esla. As regards ease of construction, the latter canal is perhaps one of the best in Spain. The whole estimated cost of the works, including a weir 191 yards long, is a little under £100,000; and for this amount 13.000 hectares, say 32,140 acres, will be perfectly irrigated at a cost of £3 2*s.* per acre, while the cost per acre of the Henares Canal is £7 7*s.* The land in the Esla valley is exceptionally rich, so much so that it is known in the country as "La rica vega de Toral"—The rich valley of Toral. It is very thickly populated; the only objection that can be made to it is its distance from any seaport. The head of the valley is, however,

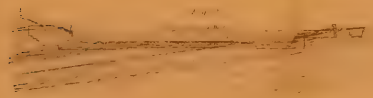
IRRIGATION IN SPAIN.

THE HENARES CANAL

Fig 1

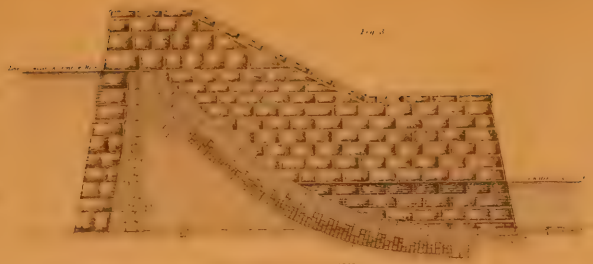
PLAN OF WEIR

Fig 2



GEOLOGICAL SECTION ON LINE OF WEIR

Fig 3



CROSS SECTION OF WEIR HENARES

Fig 4

SECTIONS OF CANAL

Fig 5

PART PLAN OF TUNNEL

Figs 7

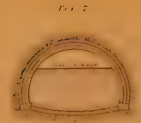
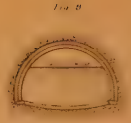


Fig 8

Fig 9

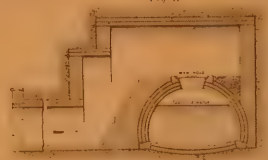


SECTIONS OF TUNNEL

Fig 10

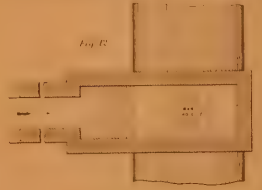
ELEVATION OF END OF AIR GALLERY

Fig 11



SECTION OF AIR GALLERY

Fig 12



PLAN OF AIR GALLERY

Fig 13

TUBE FOR CARRYING STREAMS OVER CANAL

Fig 14

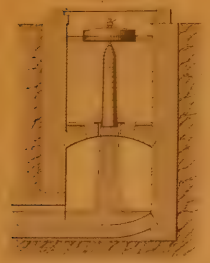
PART PLAN OF DISTRIBUTING CHANNELS

IRRIGATION IN SPAIN.

MODULES FOR MEASURING WATER.

M. RIBERA'S MODULE.

Fig. 1



VERTICAL SECTION.

ELCHE MODULE.

Fig. 2.

SECTIONAL PLAN.

Fig. 3.

TRANSVERSE SECTION.

Fig. 4.

LONGITUDINAL SECTION.

LORCA MODULE.

Fig. 5.

SECTIONAL PLAN.

Fig. 6.

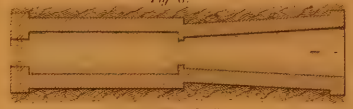
LONGITUDINAL SECTION.

MILANESE MODULE.

Fig. 7.

LONGITUDINAL SECTION.

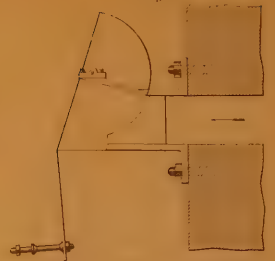
Fig. 8.



SECTIONAL PLAN.

LIEUT. CARROLL'S MODULE.

Fig. 9.



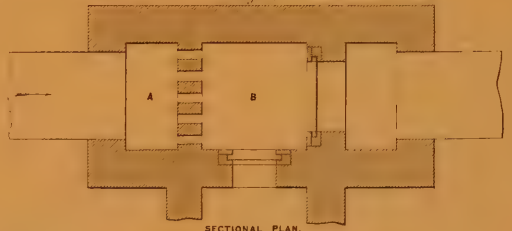
SIDE VIEW OF CAST IRON HEAD OF MODULE.

SECONDARY MODULE, HENARES CANAL.

Fig. 14.

LONGITUDINAL SECTION.

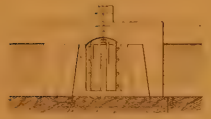
Fig. 15.



SECTIONAL PLAN.

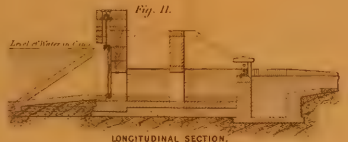
MODULE IN USE ON HENARES CANAL.

Fig. 10



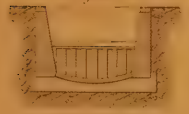
ELEVATION.

Fig. 11.



LONGITUDINAL SECTION.

Fig. 12



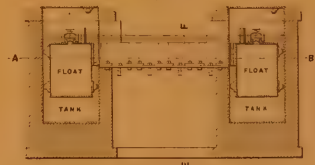
CROSS SECTION.

Fig. 13.

PLAN.

SELF-ACTING WEIR, HENARES CANAL.

Fig. 16.

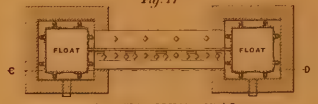


SECTION ON C D.

Fig. 18.

SECTION ON E F.

Fig. 17



HORIZONTAL SECTION ON A B.

Scale for Figs. 1 14. 15. 16. 17. 1/10 = 1/0

Scale for Figs. 2, 3, 4, 5, & 6. 1/60

Scale for Figs. 7 & 8. 1/60

Scale for Figs. 10, 11, 12, & 13. 1/12

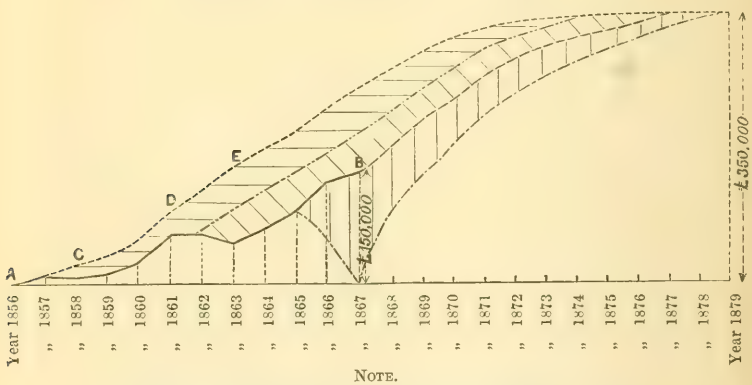
only distant 12 miles from Leon, the capital of the province, and only half that distance from the Leon and Palencia Railway, which places it in direct communication with the principal railway in Spain, and will in a short time place it also in direct communication with the ports of Gijon and Vigo. There are no works of any importance on the Esla Canal: it is thus of less interest to the Engineer, though by so much the more valuable to its proprietors.

The Paper is illustrated by a series of Diagrams, from which Plates 22 and 23 have been compiled.

Mr. Login said that in the Rechna Doab, according to the published Government Gazette of the Punjaub, the rainfall diminished from a depth of 60 inches among the hills and 30 inches at Sealkote, at one end, down to a depth of only 4 inches at the other end, on an average of four years. In one part of this district, the cultivated area returned about £200,000 a year to Government; whereas another part only returned about £50,000, owing to the want of water. From his own calculations and those of Colonel Baird Smith, the probable revenue would be £500,000 a year along this dry tract of country if irrigated—a clear proof of the value of irrigation in the Punjaub. With regard to the Western Jumna Canal, at the end of seventeen years, the revenue had paid off the 5 per cent. interest, so that at present the actual cost of the canal was £212,000; all charges, including interest, having been paid off, and there had been a clear profit of £60,000. The Eastern Jumna Canal had at present just paid off the 5 per cent. As a rule, many years elapsed before irrigation canals were remunerative; and on that account there were objections to private companies taking them in hand in Bengal and the North Western Provinces; but in the Punjaub, where the rainfall was always scanty, the circumstances were quite different. With respect to the financial state of the Ganges Canal, the black line A B (Fig. 1) showed

Fig. 1.

Financial State of the Ganges Canal.



NOTE.

The full line A B represents the actual direct revenue already received.
The Mutiny, C, occurred in the 3rd year after the opening of the Canal.
„ Famine, D, „ „ 5th „ „ „
„ Accident, E, „ „ 7th „ „ „
The loss of revenue owing to the Mutiny is estimated at £600,000, and is represented by horizontal shading.
„ „ „ Accident „ „ £365,000, „ „ diagonal shading.
„ „ that would have occurred had the Canal been remodelled £645,000, „ „ vertical shading.

the actual returns since 1856, when the canal was opened, to the

year 1867, when the direct revenue was £150,000. It was generally supposed that if there had been no mutiny, whereby the progress of the works had been stopped, and no accident, the return would have been much larger. The loss owing to the former had probably been £600,000, and to the latter about £565,000. People had lost confidence in the canal on that account; and had the remodelling scheme been carried out there would have been a further loss of upwards of £645,000; but confidence was now being restored, and he estimated that the increase of revenue would probably reach £350,000 yearly—the special Committee estimated it at £360,000. At the end of twenty-five years he calculated all charges and percentage would be paid off, and that it would be returning 8 or 9 per cent. from the sale of water, leaving out altogether the indirect returns, which would be more than double. From calculations he had made he found that the food the canal could produce, when it returned £350,000, would be sufficient for about five million human beings.

The Ganges Canal was peculiarly suitable for making experiments on the flow of water, as it was a large artificial river where the supply could be regulated, and where a volume of water equal to four times the discharge of most English rivers could be obtained. The water also flowed under many different conditions,—as over pebbles at great slopes, over falls, through bridges, and over the Solani Aqueduct; in the latter case, in two smooth uniform channels of masonry with perpendicular sides, the length of which exceeded 900 feet, and each of which was 85 feet in breadth. The floor of these channels was horizontal, and slightly below the general level. The discharge of the canal in December in 1860, when there was a depth of water of 7 feet 1 inch at the Roorkee gauge was :—

No. of Mile.	Point of Observation.	Mean Velocity in feet per Second.	Discharge in cubic feet per Second.	Remarks.
1st	Below the Regulator near Hurdwar.	5·10	6,710	At the Regulator the water was 9 feet deep. The bed was composed of pebbles, and had a slope of 2 feet per mile. The water was quite clear.
19th	Over the Solani Aqueduct, at Roorkee.	4·48	6,283	The depth of water over the floor of the Aqueduct was 8·25 feet. The water was slightly turbid.
50th	At the head of the Futtigurh Branch, above the Regulator.	3·46	5,279	There was silt on the floor of the Regulator, and the water was very turbid.

At the time these measurements were taken, a considerable volume was passing down the irrigating channels, and there was great leakage where the canal crossed the Rutmoo River. This leakage was stopped in the year 1862. There was also, and still was, a great loss of water by absorption, where the canal passed through a sandy tract of country between the thirtieth mile and the fortieth mile. The canal having been closed for a day and a half about the same time, owing to an accident on the Cawnpoor division, an opportunity was afforded, on the re-admission of the water, of ascertaining the discharge due to various depths, as the supply was increased, when the following close approximations, founded on observations taken at the Solani Aqueduct, were obtained:—

Depth at the Roorkee Gauge in Feet.	Discharge over Solani Aqueduct in cubic feet per Second.	Depth at the Roorkee Gauge in Feet.	Discharge over Solani Aqueduct in cubic feet per Second.
2	1,750	5	4,480
3	2,675	6	5,380
4	3,575	7	6,283

Subsequently a further series of experiments was made, the results of which are recorded in the following

TABLE showing the Surface, Mean, and Bottom Velocities over the SOLANI AQUEDUCT in February, 1862, when there was a depth of 7 feet of water at the Roorkee Bridge; and the proportional differences of these velocities at every 7 feet across the Channel.

Distance in feet from the left side of the Channel.	Velocity in Feet per Second.			Proportions of Differences.			Remarks.
	Surface.	Mean.	Bottom.	Surface.	Mean.	Bottom.	
0	3·00	2·80	2·60	100	93·33	86·66	The depth of water over the flooring of the aqueduct was 8·20 feet.
7	3·50	3·30	2·95	100	94·28	84·28	
14	3·85	3·60	3·25	100	93·50	84·42	
21	4·15	3·80	3·45	100	91·56	84·09	
28	4·35	4·00	3·50	100	91·95	80·46	
35	4·55	4·15	3·55	100	91·05	78·02	The slope of the surface of the water was 1·005 foot in the mile at the point of observation.
42	4·75	4·35	3·60	100	91·58	75·79	
49	4·90	4·50	3·65	100	91·86	74·49	
56	4·95	4·55	3·70	100	91·92	74·74	
63	5·00	4·55	3·75	100	91·00	75·00	
70	5·00	4·55	3·80	100	91·00	76·00	
77	4·80	4·55	3·70	100	94·79	77·08	
85	4·40	3·90	3·40	100	88·64	77·27	
	4·40	4·04	3·47	100	92·04	79·10	

The mean surface velocity equalled the greatest surface velocity multiplied by 0·88. The mean velocity of the whole section equalled the greatest surface velocity multiplied by 0·81. And the mean bottom velocity equalled the greatest surface velocity multiplied by 0·69.

In all the experiments on the Ganges Canal it was found that the observed mean velocity exceeded the calculated mean velocity; and it would be found that as the depth increased so would the difference between the surface and mean velocities decrease, and that between the surface and bottom increase.

It should be noted that, in 1860, when the water was held up only 3 feet at the Assoffnuggur Falls, 5 miles below the Solani Aqueduct, the mean velocity was 4·48 feet per second. In February 1862, when the water was held up 4 feet at the same place, the velocity was reduced to 4·04 feet per second; while in 1863, when the water was held up 5·20 feet, the velocity was only 3·76 feet per second. This reduced velocity prevented the abrasion of the bed and the falling in of the banks; and indeed portions of the bed silted up.

Sir Arthur Cotton wished to state the effect of irrigation in India when the works were properly constructed. Water was raised from millions of wells, by the native cultivators, at a great profit, or else they would not do so; and at a cost which amounted at the present time, with the present value of money, to about £1 per 3,000 cubic yards. On the Madras plan, water was distributed at about one-fiftieth part of the cost at which it could be raised and used profitably from wells, and that was the foundation of the enormous profits of irrigation works on a large scale, when properly constructed. The Godavery irrigation works cost a little over £500,000, and 800,000 acres were now irrigated; so that the capital employed had been 12*s.* an acre; and that land was at present paying to the Government a water-rate of 8*s.* per acre. The total return from these works was not so great, probably because large portions of the land were surreptitiously watered: but there was an increased revenue at present of £270,000 a year, and almost the whole of that could be shown, by comparison with unwatered districts, to be due to the irrigation. Thus the Government gained at least £250.000 a year actual increase of revenue on an expenditure of £500.000. The total quantity of water distributed was about 8,000,000,000 cubic yards for £40,000 a year (8 per cent. on a capital of £500.000), which gave 200,000 cubic yards per £1, including waste. There were three irrigated districts in India,—Tanjore, Godavery, and Kistnah; the revenue of each of which was at least double the average of the unirrigated districts. The Kistnah works were not above half completed; the Godavery works were not above three-quarters completed; and the Tanjore works were completed in a certain way. The revenue of Tanjore was £620,000 a year; of Godavery nearly £500,000; and of Kistnah about £450,000. If the other one hundred and thirty districts in India were thus improved, the revenue would be £65,000,000. True, the results of the Ganges Canal did not support these statements, but he held that the

Ganges Canal had been a total mistake in the fundamental points of its projection; and therefore, after twenty-four years, it yielded last year a revenue of only $3\frac{1}{2}$ per cent. However, both sides of the question were before the public. But this he might say, that some definite conclusions to the profits on irrigation was most essential, because upon it depended whether India was to be steeped in poverty and overrun by famine, or whether the country was to be effectually relieved from both, and whether an immense field was to be opened for civil engineers or not.

Mr. BATEMAN said, that on the same day on which Mr. Higgin's Paper was read he had gone over the Henares Canal in Spain, and therefore he could give the latest information with respect to the works. The canal was made from the joint designs of Mr. Higgin and himself, and had only recently been brought into operation. During the last twelve months there had but been 10 inches of rain in Madrid, and in the plains of Castille and La Mancha he believed the fall had been even less. The crops had suffered severely, and if it did not rain shortly the effects would be disastrous on the population generally. It was only six weeks since the water in the Henares Canal was turned upon the land in the upper part of the valley, and the manner in which the crops had revived from a state of utter prostration was most striking. Crops which were supposed to have been absolutely lost, and of which the people said that if the water would recover them it would recover anything, when he was on the ground last week looked as healthy and full coloured as crops could do. In fact, the people were quarrelling for the water, and small springs which issued from the hill sides were being turned to use, now that the advantage resulting from the application of the irrigation water was seen. The inhabitants had never thought of utilizing the small streams, until they saw how much good was done by the water of the canal. He had been engaged also on other works of great interest in several parts of Spain. In Majorca he was reclaiming from a state of waste a tract of marsh land, which had been the hot-bed of malaria, pumping out the water from that part which was below the level of the sea, draining it, and irrigating it. The value of the crop upon a certain part of that land which on the 24th August, 1866, was in a state of waste, and had never till then been touched by the hand of man, was estimated at between £30 and £40 an acre for the year. That land, however, stood higher than the general marsh, and had not been so constantly covered by water; but the value of the land, generally, when it was properly drained and irrigated, would be very great. The fee simple of land in Spain sold for from £3 or £5 to £7 or £8 when not irrigated; the same land, when watered, sold at form £60 to £200 an acre. No one could travel over the garden-ground of

Valencia, Murcia, or many other parts of the eastern and southern coasts of Spain, without being struck with the extraordinary difference in the appearance of the land which was watered and that which was not. On one side of a ditch there would be a field producing abundant crops of every sort, and on the other side, for want of water, the land would be a barren waste. In the plain of Castille, where some of the best corn in the Peninsula was grown, the ordinary cultivation was one crop in two years; but it frequently happened, from bad seasons and other causes, that there was only one crop in three years. The corn did not grow to any great height; and the straw was left standing in the ground for manure, the heads only being cut off. The land was allowed to lie fallow for one year, and then the straw was ploughed in with small one-handled ploughs. There was no pasturage, no cattle, no milk, and no butter, except on the irrigated lands. On those lands three crops,—wheat, beans, and maize, followed each other in one season; and a crop of alfalfa, which was cut nine or ten times in the course of the year, yielded £40 an acre a year. The value of the rice crop in the land around Valencia would come to £30 per acre, or even more than that. In the delta of the Ebro, where he was also reclaiming a portion of the land from a state of waste, the average value of the first or second crop of rice after the land was once watered from the River Ebro, was from £12 to £16 an acre. In growing rice only one crop was raised in the season, the land being allowed to lie fallow for the remainder of the year.

There was no striking peculiarity, that he was aware of, in the Henares Canal, except the method by which it was proposed to measure the water distributed to the landowners. The mode in which the water was distributed in the plains of Valencia originated with the Moors, when irrigation was first established in that country, and had been continued since their expulsion in the time of Ferdinand and Isabella. The whole irrigated land was divided into districts, each under the management of a syndic, and the water was turned on and distributed to the various proprietors according to rules which had been adopted as the custom of the country, and, in case of an appeal, it was heard by the Junta at the door of the Cathedral of Valencia. No records were kept; the decision of the Junta was final, and in that way the whole of the water of that vast tract of country was distributed to the advantage and satisfaction of the people. In newer canals, granted by concession from the Crown, it was found necessary to introduce another system, because it was not possible to apply a custom to them however much it had become sanctified by age in other districts. The rate to be paid for water distributed from the Henares Canal amounted, in English money, to 28*s.* an acre. For that the tenants were entitled to twelve irrigations in a year, each irrigation amounting

to 2½ inches in depth of water upon the ground, or total depth of 30 inches in the course of the year. That rate was cheerfully paid, and well it might be, because the increased value of the land was at least sevenfold, and he should be nearer the average if he said tenfold; for land which sold for £6 before irrigation, would sell for £60 after it was irrigated. The water was measured by discharging it through a sluice from the main body into a little chamber with a cross wall, pierced with apertures for the purpose of steadying the flow of the water, and destroying the velocity and disturbance occasioned by the discharge from the sluice. On the lower side of this cross wall there was a tolerably still pool. A gauge weir, consisting of a plate of iron placed across the opening, enabled the quantity discharged to be accurately calculated by well-known formulæ; and the water was discharged in greater or less quantity, according to the extent of district to be irrigated. The quantity of water to be distributed was calculated from the depth of the water flowing over the gauge plate, and by tabulating the quantity according to its depth, and publishing it in the form of tables, not only the guard who had charge of the water, but every individual in receipt of it, might know exactly the quantity of water being discharged. The details of irrigation were somewhat difficult, as care had to be taken that all the land was properly irrigated within a given period, and that the people who received the water were satisfied that they got the proper quantity, and that was a point which required most careful attention, and one which was attended with the greatest difficulty.

He had lately been considering the cost of irrigating land in the best and most effectual manner, and he found it a desirable method to divide the land into patches or parcels of about 200 mètres wide and 400 mètres long, according to the lie of the country, and to irrigate from small carriers to a distance of 100 mètres on each side. In land in which it was not possible to make the carriers water-tight by the mere earth, stone carriers had to be used; and in such cases the cost of distribution was about £3 an acre. Earthern canals, where the earth would consolidate and become water-tight, would cost much less. In some of the richer marsh lands, such as those which he was reclaiming in Majorca, the earth dried up and cracked, and there, of course, masonry carriers were necessarily made on the top of the earthern mounds, which allowed the irrigation to be carried on in the most perfect way that could be devised; where, however, as over a large portion of Spain, the material when put together and properly pounded would not crack, the cost was much less. The Henares Canal was carried through material which was, some of it, entirely gravel, but the matrix in which the gravel lay was so tight that there was hardly any loss from leakage.

In another work, the reclamation of a portion of the land at the delta of the Ebro, the ground consisted of fine disintegrated material, washed from the surface of the uplands by floods, and carried down by the Ebro and deposited on the coast. The result had been that the delta had extended some 20 miles from the main land. There was not a stone in the whole of that delta, and the soil proved most fertile where it had been cultivated. It formed a perfectly water-tight mass when put together, and that rendered the work exceedingly cheap.

The only important work on the Henares Canal was a weir across the River Henares. It had been founded on rock, and the heart of the weir was composed of concrete formed of the hydraulic lime of the district, and the front or apron of the weir was composed of ashlar taken from the neighbouring hill. It was built in a curved form, the foot abutting against the solid rock, and had sustained, uninjured, heavy floods during the time of its execution ; and for a long time one end was left open as a passage for the water. During the course of its construction, the water had in heavy flood filled the gap thus left, and passed over the top of the weir 4 feet in depth without causing any injury.

Colonel Sir William Denison remarked that India, as a general rule, was watered by periodical rains. The south-west monsoon set in at the end of May or the beginning of June, bringing a fall of rain varying from 120 inches to 300 inches, along the Western Ghauts. A portion of that rain fell over the crest of the ghauts, and was delivered by the great rivers, the Godavery, Kistnah, Cauvery, and others, into the Bay of Bengal. In October the wind veered to the north-east, and brought rain with it from the Bay of Bengal; but the amount was much smaller, varying from 30 inches to 50 inches, and on this the supply of water for the land between the east coast and the Western Ghauts depended. In the latter case the irrigation was simple. In every village situated in a valley down which the rain drained off, arrangements were made to secure as large a supply of water as possible. Every watercourse was changed by dams into a series of pools from the top to the bottom of the valley, until it might be said that the whole water was exhausted. It was, however, very different with the great body of water that came down during the south-west monsoon. That was delivered by three or four great rivers. Take the Godavery as an instance; during the south-west monsoon there was a body of water $2\frac{1}{2}$ miles or 3 miles broad, and 25 feet deep, rolling down the bed of the river. A portion of that water was stopped, and 900,000 acres had been, or would be, irrigated by it; still there was enough water going to waste to irrigate fully, at the rate of 5,000 cubic yards per acre, 9,000,000 acres. The great failing in

the peninsula of India was the want of moisture: for six months it might be said that no rain fell which could have any action on cultivation, so that unless a portion of the water of the monsoon could be retained and used for irrigation, the supply of food would not be adequate to feed the population, and famines would be of usual occurrence. A large amount of land was under cultivation, with what was termed "dry crops," such as millet, &c.; these were sown about the beginning of the monsoon, and were dependent upon the rainfall for moisture; but as soon as these were gathered, the ground, unless when water could be furnished from rivers or other sources, laid fallow for eight months.

For the staple of the country, rice, the inhabitants were dependent to a great extent on irrigation, and the water for this was the product of the monsoon—and principally of the south-west monsoon. Complaints had been made that there was a steady falling-off in the quantity of water which fell during the monsoon; and it was not difficult to understand how this must be. The Hindoos, although they did not use much wood, yet for three thousand years had been, year by year, cutting some, and no one ever thought of planting for firewood. Again, of late years, railways had been introduced, and it was found cheaper to use wood than coal for the locomotives. The consequence was that the proprietors of forests were cutting down the wood and handing it over to the Railway Companies, and the fall of rain diminished. The Government ought, therefore, to economize as much as possible the water at its disposal, and not a drop should be allowed to run into the sea until it had first paid toll in irrigating the land. It often happened, from want of means of transport and roads to convey food in sufficient quantities, that in one village there was plenty, and in another, 50 miles off, there was a famine. Railways were doing much to remedy the difficulties arising out of the deficiency of means of transport; but the object of greatest importance, in a social point of view, was to increase the yield of food, and this could only be done by irrigation.

Attempts had been made of late years to work out irrigation schemes by the intervention of Companies. The Madras Irrigation and Canal Company had taken up a scheme suggested by Sir Arthur Cotton, for utilizing the water of the Toombuddra. Government gave this Company full powers: it guaranteed 5 per cent. interest on their capital, and everything was done to help them. But a difficulty arose from the fact that the revenue of the country depended to a great extent upon the rent of the land; the rent of the land depended on the produce; and when a Company was admitted to deal with the land, and to tax the people at their will

and pleasure, for furnishing the means of raising the crops, it was certain that there would be differences of opinion, grumblings, and disputes between the Government and the Company, and between the Company and the cultivators of the land. In the case of this Company, the understanding at first was that they should accept 3 rupees, or at the utmost 4 rupees an acre for the water supplied to the ryots; but after a time the Company saw that 4 rupees would pay a very small interest on their capital, looking to the quantity of land they were irrigating, and they began to claim 6 rupees, and that was a state of things which should not exist. The Government could raise money at a much easier rate than any Company, and had the power of employing competent persons. The greater part of the revenue of India was derived from the land. Out of £40,000,000, the rent of the land amounted to upwards of £20,000,000, and the process of raising that rent was simple; but it had been mystified of late years by an attempt to make the ryot pay a sort of uniform rate for irrigated land: he had to pay 3 or 4 rupees per acre for the water; as if the same quantity of water applied to different crops or different land produced the same results, whereas the fact was that the water in one case was worth to the man not above 2 rupees, and in other cases it was worth 8 rupees. The poor man, who occupied the worst soil, was, by that means, chargeable with the heaviest rent; whilst the rich man, with the best return from his land, received a present of 3 or 4 rupees an acre, and the revenue of the country was proportionately lessened.

Mr. J. D. Barry believed that Spain was the first country that had attempted to legislate on waters in general: for the last two years great efforts had been made to encourage irrigation. The law of the 11th July, 1865, voted one hundred millions of reales, about £1,000,000, for this purpose; and a second law divided into sixteen chapters, forming a complete code of legislation on this most important element of national wealth and prosperity, was passed on the 3rd August, 1866.

By this law all enterprises of irrigation enjoyed the following privileges:—

1st. The right to open quarries, construct lime-kilns, or erect workshops on the adjoining land. If these were public or communal, no indemnity was required for the occupation; but if private property, then it was necessary to agree with the owner or mayor of the district, and a guarantee was given for the indemnity to be paid for the temporary occupation.

2nd. Exemption from the transfer of real estate, duty and registration fees.

3rd. Right of expropriating all lands required for the canals,

mills, and in general, whatever properties were necessary for the prosecution of the enterprise and works.

4th. All workmen employed had the same local privileges as the local inhabitants, and enjoyed the communial rights.

5th. The capital employed in irrigation was free from present and future taxation.

6th. By the law of the 22nd April, 1849, and ratified in that above mentioned, during the first ten years after the conclusion of the works, the enterprise was free from all taxation on the produce of their irrigation.

7th. All land brought under irrigation would only be taxed as dry during the ten years that followed the conclusion of the works. Irrigation was forced, and after agreeing with the majority of the landowners, the minority were bound, so that if any landowners refused to receive the water and pay for it, power was given to the enterprise to take his lands at 50 per cent. addition on the value he had given as the basis of taxation as dry land; and as irrigation increased the value of land from ten to twelve times, it was to the interest of an enterprise to find a large number of landowners not disposed to take the water.

He might further mention, as an illustration of the anxiety of the Spanish Government to encourage irrigation, that a law was at present before the Cortes granting a subvention of twenty-five millions of reales, £262,500, to the Royal Company of the Canal of Tamarite, of which he was the Engineer-in-Chief. This canal would irrigate 259,000 acres of valuable land, and was calculated to increase the territorial revenue of the district by £2,840,000 a year. He believed that the Henares Canal was the first work of the kind where the engineers had not lost sight of the administrative and economical question. Each distributing canal would carry the water to some 300 hectares, and one guard could attend to this and keep it in order.

For the Tamarite Canal he had calculated a supply of 400 cubic mètres per irrigation per hectare every fifteen days, after deducting for evaporation and filtration, and this corresponded to a continual flow of 0·309 of a litre, or $26\frac{3}{4}$ cubic mètres in twenty-four hours, equal to a depth of 0 m. 041. over the whole surface each irrigation, or 0 m. 521. during the whole season of one hundred and ninety-five days. In the South of France, in many cases smaller quantities were used, but the above estimates were in accordance with the views of the French authors, Nadault de Buffon and Pareto.

The following Table showed the quantity of water used by some canals, by which it would be seen what great differences existed:—

Name of Canal.	Quantity per Second.	Quantity per Irrigation.	Duration of the Irrigation Season.	Observations.
	litre.	litres.	days.	
Roussillon	0·300	350	..	
Vinca, Pyrenées orientales.	0·169	146	180	
Canal of Cavaillon	0·600	..	..	
Pyrenees orientales.	0·250	243	180	
Piedmont, Colomberve de Gallius	0·360	360	160	
Rive Saltes	0·169	146	180	
Perpignan	0·169	146	180	
Lombardy (Milan)	1·000	..	..	It was usual in
„ (Pavia)	0·750	..	..	Lombardy to
Canal de Tamarite	0·309	400	195	take more than
Principe de Asturias Don Alfonzo	0·309	400	195	was required,
Canal de Lorca (Spain)	0·330	..	..	and to sell the
Canal de Lozoya (Spain)	0·330	..	..	surplus.

The necessity for irrigation in Spain had been sufficiently explained by Mr. Bateman when he stated the fact that it increased the value of the land tenfold; but a few comparative statistics of the state in agriculture in Great Britain and Spain and some other countries would further prove this. The surface of meadow land compared with that under cultivation, was in—

Countries.	Cultivated Land.	Meadows.
Great Britain	1	1
Irrigated parts of Piedmont and Lombardy	2	1
Prussia and the principal German States	2·85	1
Bavaria	2·5	1
Austria	3	1
Holland	1·1	1
France	5	1
Spain	146·5	1

Thus in Spain the people were unable to raise horses and cattle, and deprived of the means of manuring their lands; and only by irrigation could this state of things be remedied.

Great Britain, in the year 1857, supplied food for eighty-eight inhabitants and one hundred and forty-two head of cattle per square kilometer; while Spain in the same year, with about $\frac{2}{5}$ths more surface, supported only thirty-two inhabitants and forty head of cattle: these facts could only be accounted for by the want of water.

He had lately employed ploughs with great success on the Canal del Principe de Asturias, "Don Alfonzo Pelayo," for the purpose of making the ditches for the distribution of the water. When he took charge of the works these ditches were costing, by hand labour, $2\frac{3}{4}$ reales per mètre, but since the employment of ploughs, the cost has not exceeded $\frac{1}{5}$th of a reale for the same length.

He was at present making ploughs by which he hoped to cut channels to carry 100 cubic feet of water per second. He fancied that a mixed system of irrigation-works would be best suited for India, and that canals should be constructed by private enterprise and the revenue collected by the district deputy collectors.

With regard to the belief that irrigation produced intermittent fever, he did not attribute this so much to the introduction of water to land previously dry, as to the turning up of land which had been previously desert. The fact existed, no doubt, but the remedy existed also, by the planting of the "Eucalyptus Globulus," a tree which had been largely introduced into Australia, from the Cape of Good Hope, and which had rendered districts healthy which were previously uninhabitable. This tree grew with remarkable rapidity, attained the height of 3 feet the first year, and of 12 or 13 feet the second. An infusion of the leaves was also an excellent remedy for fever. The following Table gave the cost of some of the recently-executed canals:—

Name of Canal.	Capital.	Surface Irrigated.	Cost of Irrigation per Acre.	Observations.
	£.		£. s. d.	
Canal of Urgal . . .	1,200,000	222,500	5 8 0	
„ of Henares. . .	..	30,875	7 7 0	
„ of Esla . . .	..	32,464	3 2 0	
„ of Tamarite . .	1,400,000	258,979	5 8 1	In construction
„ de la Vanne . .	120,000	5,000	24 0 0	
„ des Alpines . .	132,000	76,860	1 15 4	
„ del Principe de Asturias Don Alfonzo .	700,000	173,000	4 5 0	In construction

In reference to the construction of dams, he would describe the dam and tunnel of the Laguna del Rey (Plate 24). The waters of the several springs which formed the river of the upper Guadiana, at no great distance from their source, were collected in thirteen large natural reservoirs, or lakes, called in Spanish "Lagunas." Of these the Laguna del Rey and the Laguna de la Colgada were the lower and most important. They were separated by a thin slip of rock about 30 mètres in thickness, and there was not more than 2 feet difference in the level of the surface of the waters. When these works were finished, they would form one large reservoir, with a superficial area of 174 hectares, or 430 English acres, containing sixty millions of cubic mètres of water in reserve, besides the natural flow of the river, which at a minimum was $5\frac{1}{2}$ cubic mètres per second, or at the rate of four hundred and twenty-five thousand two hundred cubic mètres in twenty-four hours. The works consisted of a dam of hydraulic masonry, 511 mètres long and 15 mètres high, founded on the solid rock and abutting at each end on the adjoining mountains.

The form was slightly curved, with the convex side towards the water. The masonry alone was calculated to resist the pressure of the water, and the curve shown in the transverse section, Fig. 3, indicated the theoretical line independently of the earthwork. The masonry was further strengthened by a bank of punned earthwork, which gave a great excess of stability, and thus placed the safety of the work beyond all risk. At convenient places provision had been made for an overflow weir, 2·5 mètres in width, the top of which would be 1 mètre lower than the dam, and thus all danger of the waters passing over the top of this structure was effectually avoided. At a depth of 35 mètres below the highest level of the water, a tunnel would give passage to all the waters required for irrigation, and provision was made for the discharge of from 8 to 40 cubic mètres of water per second. The sluice-gates were situated at the mouth of the tunnel (Figs. 5 to 14), inside of which was a well to collect any stones or gravel that might come down. There were two sluice-gates, but it was intended to use the outside ones only, and to reserve the inner ones in case repairs were required. They were designed after the plans of those used by the Moors more than six hundred years ago, which had worked perfectly ever since. They were worked by a rack and pinion, and one man raised and lowered them easily. At the outlet of the tunnel there was a small cutting communicating with the present watercourse, and which would be used until the new one, now in course of construction, was ready. From this point to the mill of Santa Maria, a distance of 17 miles lower down the valley, the distributing channels for the irrigation of 30,000 acres, were nearly finished. It was estimated that this work would cost, when completed—

Dam.	Reales.	Reales.
1. Wall in masonry	2,783,058·86	
2. Overflow weir	190,485·30	
3. Retaining wall	34,384·20	
4. Bank against masonry	279,353·00	
		3,287,281·36
Tunnel.		
5. Shaft	879,084·24	
6. Well for collection of stones	56,980·50	
7. Sluice gates and chambers	285,694·20	
8. Cutting deep passage between the two lakes	391,248·00	
		1,613,006·94
		4,900,288·30
Incidental expenses, 10 per cent.	.. ..	490,028·83
Total Reales	.. ..	5,390,317·13
Or at 95 Reales per £, equal to	.. ..	£56,740 4 0

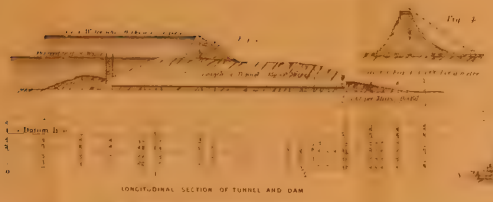
Mr. KILGOUR had been for some time in charge of a portion of the Baree Doab Canal, and would give a description of a type of fall there in use. He would mention the desiderata for a perfect fall. Presuming that, with due regard to the nature of the ground, and the amount of silt in suspension, the proportion between the hydraulic mean depth and the slope of the ground had been adjusted, both above and below the fall, so as to preserve the bed from either scour or deposit, it was evident that a perfect masonry fall was one, that preserved the normal gradient of the canal and surface of the water above the fall, that prevented the water in its descent from acquiring an undue velocity in the direction of its course, and that gave rise to no swirl or eddy below the fall. In other words, were it possible to remove the fall and raise the bed of the canal below to the level of that above, no change should be created in the regimen. The best way of effecting this was by means of balks of timber with fan-shaped apertures, the invention of Colonel Dyas of the Royal Engineers; but, owing to the difficulty of preserving timber in India when alternately wet and dry, the expense of keeping them free from floating rubbish, and some other minor points, they were not considered altogether satisfactory. The subject had been much discussed and experimented upon, and many falls had been constructed, and were successful. Above the fall the normal slope of the bed and surface of the water was preserved for all conditions of discharge by diaphragms. The vertical fall of the water, aided by the spreading effect of the curved lip, prevented any undue momentum in the down stream direction, the water in the basin below acting as a cushion, and together with the circular form of chamber, greatly diminishing the eddy. One slight difficulty might be mentioned with regard to the basins; loose bricks were apt to get into them, and then, finding a bed under the fall itself, adopted a rotary motion, soon cutting a funnel-shaped hole in the brick floor, which got smaller as the foreign objects wore out. To remedy this, the canal being in work, planking was placed under the fall on the floor of the basin, but it would be better, in new works, to give the basin a slope towards the down stream end, where the water had little or no rotary motion.

On the question whether irrigation canals in India should be worked by Government or by private companies, his experience led him to agree with Sir William Denison. He believed that the method adopted of charging by the quantity of land irrigated was really the most satisfactory, as there was a difficulty in getting a sufficiently inexpensive, durable, and accurate module, and there was a saving of expense by the acreage measurement, the complications of the land and water rent did not occur, and last, but not least, it did not raise the difficulty of having to persuade the native cultivator that he got the quantity of water he paid

IRRIGATION IN SPAIN.

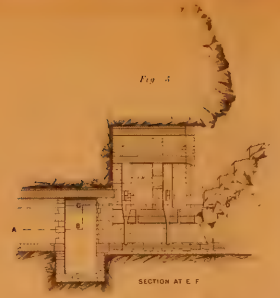
TUNNEL AND DAM AT LAGUNA DEL REY

GENERAL PLAN OF DAM AND LAGUNAS

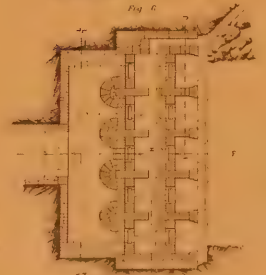


LONGITUDINAL SECTION OF TUNNEL AND DAM

CROSS SECTION OF DAM

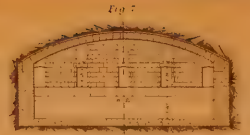


SECTION AT E F



SECTION AT A B C D

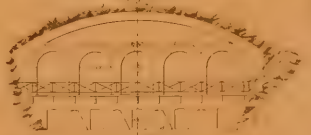
SLUICE GATES AT OUTLET OF TUNNEL LAGUNA DEL REY



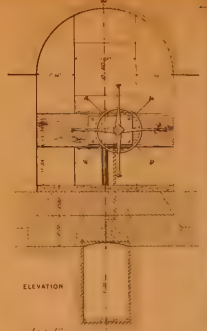
SECTIONAL ELEVATION AT I K

SECTIONAL ELEVATION AT H L

SECTION AT G H J

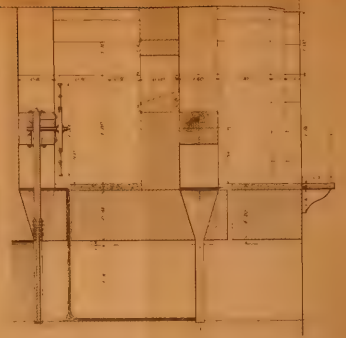


GATEWAY ELEVATION

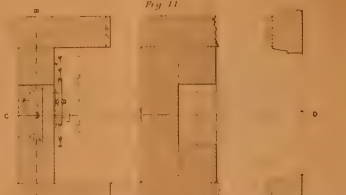


ELEVATION

SECTION AT A B



SECTION AT C D



for. He could understand the number of beegahs he had under irrigation, but heads of water expressed in inches to the third place of decimals never convinced him. Too much in the habit of trying to make as much as possible out of the European, he started with the belief that the European was endeavouring to get as much as possible out of him.

The physical features of the Punjaub rendered it peculiarly fit for canal irrigation. The hills in the north afforded admirable positions for head works, whilst the rivers at that point had lost but little water from evaporation, the supply itself being ample in the hot weather, owing to the melting of the Himalayan snows. The configuration of the country in successive doabs offered the water-shed as the most desirable line for a canal from which the land could be irrigated by simple gravitation on both sides; and the silt in suspension was invaluable as a manure in a district where, owing to the scarcity of timber, the dung of cattle was mixed with clay, sun-dried, and employed as fuel.

Water, moreover, in many parts did not occur within 40 feet, and sometimes 60 feet of the surface, besides which the wells over large districts were useless for all purposes after a few years, the water becoming impregnated with kullur, a sort of saltpetre, which rendered it unfit for drinking purposes, and destructive to cultivation. The natives had been accustomed to irrigation from the earliest dates, and there were remains of many large works of this nature throughout the country, together with the ruins of large towns. When, from constant disturbances and want of order, these works fell into decay, the inhabitants migrated to the banks of the nearest river, but would at once return had they the opportunity. Indeed, throughout the entire Presidency, the universally-expressed wish was for an ample and constant supply of good water.

Captain W. R. Johnson, who had been in charge of irrigation works in India for the last fourteen years, remarked that the distribution of water for the purposes of irrigation was a most difficult question. For rice cultivation it was generally considered necessary to give a half-inch stratum of water every day; but the necessary quantity varied greatly for different descriptions of land. In Mysore, for instance, which was a hilly country, the cultivated area between the canals and the rivers had generally a considerable fall towards the latter, and where the soil was of a sandy or open nature, the water percolated through it almost as fast as it was poured on; and in such cases much more water was required than on an argillaceous flat, which when once thoroughly saturated, and covered with water, lost little except by evaporation.

It was difficult to prevent the ryots wasting the water. To show how averse they were to a limit being placed on their expenditure, he might state that the masonry sluices, constructed on some of the

canals he had charge of, had been systematically broken up by them almost as soon as completed. To remedy this state of affairs, he had lately recommended that the land and water cess should be kept distinct, that a fair price should be fixed for the water according to any unit of measurement that might be most convenient, and that the ryots should then be allowed to have as much as they liked, upon paying for the same. This, in his opinion, was the only way to stop the complaints of insufficiency of water, and at the same time to prevent the ryots from taking more than they wanted. This scheme had been submitted for the opinion of the revenue and some of the engineer officers in the province, who, he was sorry to say, came to the conclusion that, though the best plan theoretically, it could not be carried out practically. He thought differently, and hoped in course of time some similar system would be introduced.

As to the great want of irrigation works in India, he could only speak of Mysore. There, in the irrigated districts, existing works were so numerous that it would be almost impossible to construct any new work that would not interfere with some at present in action, or out of repair. These works were generally dilapidated, and the majority actually unsafe. All the money that could be spared was required for their improvement, or restoration, and it was not, therefore, to be wondered at that, under such circumstances, Government were slow in proposing new projects.

These remarks applied to ordinary works in irrigated districts. For the extraordinary projects proposed for other parts, extraordinary measures must be taken to raise the funds. Many of them would doubtless be of the greatest benefit to the country, and it was much to be hoped that they would be carried out.

Mr. John Jones thought that works of irrigation were important, not only abroad, but even in this country He knew a valley in Wales where the land was worth £1 10*s.* an acre without irrigation, but was made worth £5 an acre by irrigation. The farmers from the neighbouring flat country in Shropshire occasionally came up into the valley, and he had heard them discussing, with the farmers of the valley, the comparative value of what was called the white water and the black water, the white water being the pure water, and the black water the farmyard liquid manure. And though in the opinion of the Shropshire farmers there was no value in the pure water, the experience of centuries proved that the land received no other nutrition than it afforded, and it was yielding good crops. In the Welsh districts there was the further advantage of the water keeping the land warm in frosty weather. In parts of the valley over which the water flowed, the grass below continued to grow, while in parts where it did not flow, the vegetation was checked by the frost.

He was, unfortunately, one of those who believed some of the magnificent promises held forth by engineers, and he belonged to an Indian Irrigation Company. According to the views of the engineer who projected it, he had expected to get 30 per cent. or 40 per cent. on his investment; but hitherto the company had not been able to earn enough to pay 5 per cent.

Another point to be considered was, whether water which came out of tanks, and which had deposited a large quantity of what it had held in suspension as organic matter, was capable of furnishing fertilising materials. He could understand water bringing down fertilising materials from the hills; but if that water was allowed to settle in tanks, as in the Indian system, and there deposited for a month or two, the sediment, it originally held in suspension, and was subject to the decomposing action of a tropical sun, he questioned whether it would continue to supply fertilising materials. He had heard that the tank-water was not considered by the natives so valuable as the water which came down charged with mud.

Mr. Vignoles, Vice-President, observed that irrigation had been carried on from the very earliest period, long antecedent to Nineveh. It had been transmitted by the Semitic nations from generation to generation, until it was introduced into Spain, and at this moment nothing was better in that country than the system of irrigation introduced by the Moors. But there was no record of works of irrigation having been otherwise beneficial than to the inhabitants of the country where they were carried on. As commercial speculations they had always been failures. He was of opinion that, as a rule, the reputation of an engineer in this country depended upon the success of his works as commercial speculations; and though he held that engineers should not look to that alone as their guiding principle, yet they should never seek to induce capitalists to embark in undertakings until the expense of first construction and ultimate maintenance and beneficial returns had been fully considered; and he was sorry to say that the commercial results of works of irrigation had not been encouraging, except in a few exceptional instances. In very many cases, though the people were willing to get the advantage of the water, they were very unwilling to pay for it.

General Balfour had great confidence in the beneficial results of irrigation works in India, if carried out in such a manner as to admit of the science and knowledge of European engineers being brought to bear on the construction of the works.

He had, during the course of his service, been a member of a Commission specially appointed to investigate the subject of public works in India; but the recommendations made by that Commission sixteen years ago, were only now beginning to be carried out.

He had formed a high appreciation of the benefits to be derived from irrigation in India, mainly from the investigation made by that Commission of the results of the works carried out under Sir Arthur Cotton, whose labours on behalf of India could not be too highly spoken of.

The extent of the benefits thus conferred on a portion of the Madras Presidency was at length beginning to be generally recognised, even in this country; but would probably be far more highly appreciated by the next generation. The two distinct questions of engineering results, and revenue results, were necessarily mixed up. Some difficulty might be experienced in raising the revenue from land irrigated by water supplied from irrigation works; but it did not appear that the people of India were adverse to the revenue being collected by the servants of a company. Neither was it in any way necessary that the works should remain in the hands of any company after their completion. The essential point was, that the works should be efficiently constructed. The question of constructing public works in India, in a more rapid manner than had hitherto been done by Government alone, was daily coming more prominently before the public.

He might observe, that Mr. Allan Wilson had for several years been engaged, mainly on works connected with irrigation, in a part of India where he had peculiar facilities for making a close personal investigation of the grand irrigation works formerly executed under the more enlightened rulers of India; and had been enabled, by means of the knowledge thus acquired, combined with his personal experience in the construction and results of irrigation works, to form definite views as to the best means of carrying out a complete system of irrigation. Having had the opportunity of personally examining the results of Mr. Wilson's labours in the Nizam's territories, he fully concurred in the views formed by him on the subject.

He earnestly desired to see more vigorous action in this matter taken by the Government. It was admitted that they were even now only beginning to obtain the necessary funds; and he thought that the great object was how to promote the cause of irrigation in such a manner, as to lead to the means required for carrying out the works being more promptly placed at the disposal of Government.

Mr. John Dickinson would confine himself to one point of the discussion, viz., whether irrigation and navigation works in India had better be constructed by Government agency or by private enterprise? But that point was most important to the public, and the corps of Engineers had a strong professional interest in it. Private enterprise had been objected to by a high authority, on the ground that the Government of India derived so large a portion of its revenue from the land, and had such close relations with

the cultivators; and it had been said that the Government was the proprietor of the soil in India, and therefore ought to construct these works, in preference to companies. Yet it was an established historical fact, that Government was not the proprietor of the soil in India; this had been proved by official revenue surveys, and by the works of scholars, such as "Briggs on the Land Tax," among others by a "Report on the Tenures of the Deccan," by Colonel Sykes, printed as a Parliamentary paper in 1866. The Government had only the same right in India as it had in this country, to tax the produce of the soil; not to take the rent of every house or field, but to take a fixed proportion of that rent. And even supposing the Government were the universal landlord in India, it would still be its interest to encourage private enterprise to develop those resources of its estate which it had been unable to develop itself. It would still be its interest to give a company an improving lease for twenty years, as it had done in Orissa, to insure the construction of irrigation and navigation works in the province, reserving to itself the right to buy up the company's works at the end of that term at the market price, if it then appeared for the public interest to do so, and receiving a specified share of the company's profits as payment for the concession of its water privileges by the State. Moreover, if the Government had such great power over the cultivators as had been described, it was an additional reason why it should not undertake the purely commercial speculation of supplying them with a necessary of life, as water was in India, if private parties offered to do it. He knew that Government had been warned by one or more of its best revenue officers, that irrigation was such a purely commercial speculation, that Government could not hope to retain a monopoly of it, and had better prepare at once for transferring the business to third parties, and assume the more dignified position of supreme arbiter between such parties and the ryots.

Again, it had often been objected, that Government had so much power in the interior of India that it could ruin any irrigation company by its hostility. Of course it could; but that applied to any other private enterprise in the interior just as much as to irrigation companies. He did not believe that Government would ruin them, if public opinion was in their favour at home as much as it was in India. The harmony and co-operation between the Government officials and the Irrigation Company's servants in Orissa had been quite remarkable. No doubt this co-operation was essential to the success of the company, as it was obliged by its contract to sell water direct to the Government, and not to the ryots, and virtually to leave the Government absolute power over its supply, and over the prices charged for it. But such dependence would not be dangerous as long as the company continued to

render great public and private services, and to receive constant praise from the local officials, as it had done hitherto.

The most striking result of this discussion appeared to be, the unanimous admission of the great profits of irrigation works. But this must have suggested to every one the question, if these works were so profitable in India, why had they not been made? Why had the Government only undertaken them in a few favoured spots; and then only after repeated famines in the same locality, and through the intense efforts of powerful individuals, as in the North West Provinces and Madras; or else where it was necessary to find congenial employment for a recently-conquered and still formidable population, as in the Punjaub? Why had only a fraction of the country the benefit of these profitable works? Why was it that, out of 509,000,000 acres in British India, of which at least 250,000,000 were susceptible of irrigation, not one-fiftieth part, not 9,000,000 acres, were yet even in a course of being supplied with these works? Why was it that, when it had been computed by experienced Engineers that 150,000,000 acres might be supplied with irrigation and navigation as easily as the deltas that had been taken in hand; and half that quantity, or 75,000,000, would yield profits equal to the net revenue of India, less the opium duty, which was paid by China; still Government had not constructed the works? And if the work had not been done, why was it not doing?

Surely if the principle of Government agency, after having been tried for about a century, had failed so signally to do the work required of it, and that under all sorts of rulers, the fault, if there were one, must be rather in the principle than in the men; and if, on the contrary, the most feeble and imperfect application of the principle of private enterprise at once produced such results as never were seen before in British India, it must raise a strong presumption that one principle was better than the other. He would show in two instances, that there was this vital difference in the results of the two principles.

First, in the case of the railways: though he considered a guaranteed company a very imperfect application of the principle of private enterprise, because the Government really was, or fancied itself, obliged in self-defence to reserve such powers of control over its operations and expenditure that it really left the company no independence at all; and, because it was found in practice that such companies cared for nothing but their guaranteed interest; they wanted that mainspring of private enterprise, the desire for profit and the dread of loss; yet even this imperfect application of the principle had drawn out an amount of private capital, and applied it to the development of India, an amount now approaching

£100,000,000, which the Government had never attempted to raise for public works.

Secondly, in the single instance in which a really independent company had undertaken to construct irrigation and navigation works, in the province of Orissa, it had spent during the four years it had been constructing its works, after making every allowance for Government charges not apparent in the accounts, fully six times as much as the highest sum allowed by Government to any work in the neighbouring Presidency of Madras; that was, above £200,000 a year against £30,000 a year; and of course with a corresponding rapidity in the progress of its works, which were now advanced enough to secure the province for the future against those famines which used to desolate it periodically, and of which the last, in the year 1866, was now reckoned by the latest official calculations to have cost the lives of one million human beings, in Orissa and its hill districts alone, with a corresponding destruction of cattle and agricultural capital.

But it was said by one of the highest professional authorities, that admitting the profits of irrigation works, admitting that they often raised the value of land tenfold, and admitting their great utility to the countries where they were introduced, still the private speculators who constructed them were always ruined, because the people would not use the water when it was offered them. Now he thought this referred exclusively to Italy and Spain; such a conclusion could hardly be applied to India. He admitted that the experiment of the single independent company yet started for these works in India was not concluded: but he would observe that it seemed to be a law of nature that every great improvement should meet with opposition, in every age and country, and even that the obstinacy and hostility of the opposition should be proportioned to the ignorance of the people to whom the improvement was offered. He admitted, therefore, that if irrigation were taken to a people who were not used to it, there would be opposition. It was quite a different thing in India, where the inhabitants were used to it; when once they had learnt its profits practically, they would take as much water as could be given them, and when their own countrymen supplied it, from village tanks or wells, &c., they made their fellow ryots pay far higher prices than any Englishman ever thought of asking. However, admitting the fact of this opposition, he saw nothing in it but what was to be expected, and nothing that a little patience and tact could not get over. In the case of the Orissa Company, the first season they had any appreciable quantity of land, about 50,000 acres, under command of irrigation, was in the famine year of 1866, and then the people gave a plausible reason for not using the water. A new assessment of the

land-tax was impending in the province, and a popular saying at the time become famous, which was this: "It is better that one or two of us should die of famine in each family, than that, by using irrigation for our land, we should give the Government an excuse for raising its tax on ourselves and our children, for generations to come." This popular saying not only provoked severe comments from the local press, but from papers at home, and in the end the Government renewed the old settlement as it stood, for another term of twenty years; but the notification of this decision did not appear in the Calcutta Gazette till the month of February, 1867; so that there was every reason to suppose that the above reason did really prevent the use of irrigation to any extent during the season of 1866-67. But after the monsoon of 1867, when the Company had about 150,000 acres under command, the people still refused to use the water, perhaps not one-tenth of the land was taken up, and so matters remained till the end of the year. He could not account for this; he could only say no Englishman in the province ever doubted that the inhabitants would use the water ultimately. Perhaps one reason was that the rains were abundant and timely that year, and perhaps the people thought that if they held off a little longer, the water-rates would be lowered. If so they were right, for after the turn of the year the rates were lowered considerably, and then at last they began to take irrigation freely. By the last accounts from the province they were taking up the land at the rate of from 2,000 to 5,000 acres per day, on yearly leases; they were supposed to have taken at least 50,000 acres this spring, and were now used to the water, and if they went on at the same rate after the next monsoon, when the company would have above 200,000 acres under command, the complete success of these works would be established in the third season of their coming into operation, which he did not think was a result that should discourage private enterprise, or ruin any company. He had now mentioned two of the greatest advantages of private enterprise over Government agency; first, its capacity for getting at private capital, and raising such an amount of it as the Government had never attempted to raise for public works, and he believed never would be permitted to raise, owing to the jealousy of capitalists and of the Chancellor of the Exchequer; and of raising it in the most convenient way, by calls that only provided for a few months' expenditure, instead of raising large loans at once as a Government must do, and then keeping the money idle till it was wanted; and secondly, its construction of the works, for its own interest, fully six times as fast as the Government rate of construction. This advantage, which was of vital importance to the people, was likely to be increased in future, for in the case of the Orissa Com-

pany the engineers had always been urging the Directors to spend money faster, and to use all the available labour, on the ground that it would prevent accumulation of interest and hasten profits; and when experience proved the wisdom of this advice, Directors would find it easier in future to call up their capital faster.

There were several other advantages of private enterprise. 1st, It was a source of constant complaint in the native press of India, that gross injuries were done to the people by Government servants in the construction of public works, without the possibility of getting any redress for them: and this was admitted in one of the published papers of Sir Arthur Cotton, who had done his utmost, but quite in vain, to get justice done to some of these victims. Now in the case of a company he was quite sure that no man would have his land taken away, or his house knocked down, without getting ample compensation from a Government tribunal. 2nd, It was stated on official authority in 1866, that in the only two cases in which companies were then ready to sell water to the ryots, the Government officers reported that the ryots so much preferred to deal directly with the company's servants, instead of through themselves, that they had better be allowed to do so. 3rd, In the charge for water, the rates of the company in Orissa were fixed by the Government at an amount much below that charged by itself anywhere else in India, and also below that charged by the natives to each other; yet the company was perfectly satisfied with the rates thus fixed, and had even lowered them as a temporary measure. 4th, There was a great advantage in planning the works so as to accommodate the most urgent wants of the people; because a company, depending on the spontaneous custom of the people for its profits, must study the wants of the people, and construct such works as they most required, and were most willing to pay for. Government was not under the same obligation; and there were two remarkable proofs of it at the present time. When, in 1852, the Government was compelled by the agitation in this country on account of its neglect of public works, to take some step to retrieve its character, it suddenly took up a scheme of railways, and for the last fifteen years had concentrated its financial force upon them. If the wants of the people had been the first consideration, Government would have undertaken works of irrigation and navigation at least *pari passu* with railways, as being more necessary to the people and remunerative to the Government; and would thus have prevented another two millions of human beings from perishing of famine during the last fifteen years, with a corresponding loss of revenue and private capital. Again, there had been loud and growing complaints of late years of the municipal taxation of India, that a second imperial taxation was being levied in the shape of municipal duties, although the wishes and the wants of

the people were not in the least consulted in municipal expenditure. Now a company depending on the people's spontaneous payments for the use of its works would be forced to construct such works as the people wanted, as it could not afford to disregard their wants and wishes as the Government did.

The last advantage he should mention of private enterprise was that, from its always following the requirements of the people, instead of attempting to dictate them, its armies of workmen were always easily diverted to other occupations, and absorbed into the general population when their temporary work was done. But this could not be the case with a Government. The immense engineering staff and establishments which the Government must form, to spend £5,000,000 or £6,000,000 a-year on hydraulic works, would remain a permanent charge on the State when the work was done; and besides the difficulty of disposing of the officers, it would become, as in France, a serious political consideration to discharge suddenly a host of well-paid State labourers.

For these various reasons he had come to the conclusion, that the development of irrigation and navigation in India had better be carried out by companies, and not by the Government.

In conclusion, he would observe that this was not the first time the battle of private enterprise had been fought in India. In 1813 the most plausible arguments, backed by the highest authority, were addressed to the House of Commons against opening to private enterprise the trade of India and China. It was said that the East India Company's "paternal Government" could manage the trade better, and make the most of it, and could not spare its profits. Luckily the House was not persuaded, and bit by bit it opened the trade, first to China and then to India. The result had been that the exports to India, which were to the value of £3,000,000 in 1813, had risen, in spite of a great reduction in prices, to between £20,000,000 and £30,000,000 at the present time; and Colonel Baird Smith reported a few years ago, that every mile of cheap transit that was opened in India opened a fresh market to English goods. The same change would come whenever this country decided that the commercial speculation of Indian hydraulic works should be really opened to private enterprise; for hitherto the Government had jealously reserved its monopoly of these works, with the exception of two experimental companies established by Lord Canning, and which it was now proposed to suppress.

Lieutenant C. C. S. Moncrieff, R.E., was of opinion that in India there was room for all parties; and that a long time would elapse before a sufficient amount of money would be sent out from England to afford means for irrigating the whole area of India, which was susceptible of irrigation. In the meantime there need be no controversy as to whether private enterprise or Government

assistance were preferable. Mr. Maine, the author of the celebrated work on Ancient Law, who was sent out to India as legal member of the Governor-General's Council—a man who could be accused of no tendency to Indian Government traditions—opposed the idea of irrigation being undertaken by companies on somewhat the following argument:—Suppose the City of London to be dependent for the carriage of every item of its food upon one single line of railway, would the management of it be ever intrusted to one company? He would not say whether that was a conclusive argument or not, but it was at least one worthy of consideration. An irrigation canal was in the time of famine the one source from which the food of the country was derived. Was it right that that source should be independent of the Government? He was not aware that any element of the success of canal companies in Orissa depended upon circumstances not equally applicable to works undertaken by the Government; and if the Government works were placed under better management, he did not see why they should not be as successful as those of the companies. He thought that every Anglo-Indian would be glad to see the companies undertake their share in the work; but that it would be a great pity that the Government should altogether withdraw.

Sir Arthur Cotton, as he had been employed for forty years upon the water-works of India, would not say one word which was not the result of actual bonâ fide experience of the best kind. The opinion had been expressed that no great profits could for many years be expected from the system of irrigation. That opinion had been founded upon the results of works in Spain and Italy, and of the Ganges Canal, which was now yielding a profit of $3\frac{1}{2}$ per cent. per annum. But his experience, derived from works of thirty and forty years' standing, was directly the reverse. He apprehended that the great test of any material work was whether it was capable of yielding direct money profit, and that if it was not, it was not a sound engineering work. According to the returns for the year 1862-3, published in the "Indian Government Gazette" in Calcutta in 1865, the results of the great irrigation works under the Government might be thus recorded:—The cost of the Ganges Canal was £2,000,000, and the loss that year, after paying its expenses, was £18,000, or an actual loss of 1 per cent. The results of the last year showed an actual profit of $3\frac{1}{2}$ per cent. The Godavery works had cost £537,000, and the profit for the year was £160,000, or 47 per cent. The Kistnah works, about one-fifth only being completed, had cost £191,000, and the profits were £29,000, or 15 per cent. The Upper Colleroon anicut, executed thirty-two years ago, had cost £24,000, and the amount of profit in that year was £64,000, or 270 per cent. The Lower Colleroon anicut had cost £34,000, and the profits amounted to £52,000, or

150 per cent. The total aggregate profits on the Madras works, over and above 4 per cent. interest, was thus stated:—

	£.
Upper Colleroon Anicut	1,168,000
Lower ditto	643,000
Kistnah	59,000
Godavery	950,000
Total . . .	£2,820,000

on a total cost of £560,000, or five times the cost of the works after paying interest and cost of repairs: two of them were still unfinished, and the Kistnah only as yet irrigating about one-fourth of the land commanded by the anicut. These were the returns published by the Government of India for 1862-3. This was the actual additional rate paid on account of the water. But, with respect to the Ganges Canal, the commissioner stated that there was reason to believe that there had been an increase in the land-tax of $1\frac{1}{2}$ per cent., which would raise the profit to 5 per cent., or the ordinary rate of interest on money, for the first time since the works were begun in the year 1844. Now, which was to be taken as a fair type of the cost of irrigation in India, the Ganges Canal or the four or five works in Madras, to which he had referred?

With regard to the cost of water on the Godavery, one and a half million cubic yards of water per hour were conveyed by canals under the Godavery irrigation for six months in the year, and about two-thirds of a million cubic yards per hour for the remaining six months, making a total of 9,000,000,000 cubic yards distributed in the year. The cost of those works up to the present time had been about £500,000. The interest and repairs at 8 per cent. amounted to £40,000 per annum, so that the cost of water was £4. 10s. per 1,000,000 cubic yards, or 220,000 cubic yards for £1. Within the last ten or fifteen years there had been a diminution in the value of money of about 50 per cent., and this should always be borne in mind. At the time those works were executed the cost of raising water from wells was £1 per 4,000 cubic yards, which was more than fifty times the cost of distributing it by the Government works. The cost of the Ganges Canal had been £2,000,000. The flow of water in the canal during the last year had been at the rate of half a million cubic yards per hour, so that the cost was £40 per million cubic yards, or 25,000 cubic yards per £1 against 220,000 cubic yards for £1 in the Godavery, which was nine times as expensive as there. The value of water was clearly shown to be more than £1 per 3,000 cubic yards at present, because that was the cost at which it was now actually raised from millions of wells all over the Peninsula for sugar and other valuable products, and it would not, of course, be

so raised if it were not profitable. The full value might also be calculated from the increase in the value of the crop due to irrigation, which in the Godavery was about £2 per acre, using 6,000 cubic yards of water, or £1 for 3,000 cubic yards when rice was grown. The water, of course, produced a greater profit when it was used for sugar, chilies, and products of that sort, which were of higher value than rice. The price paid by the cultivator to the Government being £1 for 15,000 cubic yards, they paid about one-fifth of what it cost them to raise water from the wells.

He wished next to refer to a difficulty which was said to have arisen in Orissa of the people objecting to take the water. His experience, on the contrary, was that the natives were clamorous to ascertain how soon the water would reach their land; his great difficulty had been with the Government and with Europeans, and never with the natives.

As to the cost of the great irrigation-works in India, Sir Arthur Cotton stated that the length of the great weir at that point where the River Godavery was crossed by a dam was altogether 7,000 yards, of which 4,000 yards were in deep channels, and 3,000 in low lands. The low lands had been embanked, and the channels crossed by heavy masonry dams. The case was similar in all the other rivers which had been used for irrigation in Madras. Measuring by the volume of water that passed down the river, the cost of such a masonry weir per million cubic yards per hour in the

	£.
Upper Colleroon was	375
Lower Colleroon	300
Pennair	300
Pallaur	500
Godavery	425
Kistnah	400
Beropa in Orissa	800
Mahanuddy	800
Average	£500

So that, taking the case of the Godavery, in which 200,000,000 cubic yards of water passed per hour, as the weir cost £425 per 1,000,000 cubic yards, the actual cost of the weir was £85,000. In judging of the cost, the difference of the value of money in England and in India should not be overlooked. At the time that the Godavery works were executed, the proportion was about 5 to 1, so that £85,000 in India would be equal to about £400,000 in England. The proportionate value at the present time was about 3 or 3½ to 1.

The strongest point that had been urged against private enterprise was that the ryots would be at the mercy of a private company, and that, therefore, the Government should keep the works in its own hands, in order to protect them. That the

theory; experience proved the reverse. His difficulty had been to defend the ryots, because they had the water from the Government. After having cut channels through estates, he had found it hard to induce the Government to order the payment of compensation for the land destroyed. From an extensive intercourse with the natives, he knew their views; and he agreed with what had been already stated, that the natives would give the preference to a company. If Government, in executing the works, did anything wrong, the natives had no appeal; whereas there would be an appeal from the company to the Government, and then the bias of the Government would always be in favour of the ryots. He was glad to have had an opportunity, even in an imperfect way, of bringing so important a matter before the Institution; and, though he would not pretend to decide the question as between private enterprise and Government assistance, yet he could state that the principal objection raised by those who were opposed to private companies did not exist, so far as his experience afforded him an opportunity of forming an opinion. He did not undertake to say that the interests of the country required that the works should be executed entirely by private companies, and not by Government; and he should be sorry to stop altogether the execution of works by the Government, because he was anxious to see a beneficial system of irrigation adopted throughout the country by any means. He had known districts raised from the lowest state of poverty to great prosperity by irrigation; and there was not a district in India which might not be extensively benefited by the same means. The revenue was a good test of the state of prosperity of a district in India. That of Tanjore was £620,000 a year, of Godavery nearly £500,000, and of Kistnah, £450,000; whereas the average amount of revenue of the remaining one hundred and thirty districts was £250,000, and this difference was mainly owing to irrigation. The two irrigation companies at present in existence in India had begun the first works under a guarantee of 5 per cent.; and, taking courage from that, they commenced another set of works without any guarantee. However, before the works were in operation, the companies ran aground with their estimates, principally in consequence of the enormous change in the value of money; the works were costing 50 per cent. more than when they were estimated. They then applied to Government to extend the guarantee, or to lend them the money upon certain terms. Both works were now beginning to be in operation: the Orissa works already provided water for about 200,000 acres, and a large tract of land had been taken up by the natives, so that the company had every reason to believe that they were on the eve of realizing ample returns. He considered the Orissa works a most

sound and valuable project in every way, and promising the same profits as the Madras works.

Mr. Brereton observed that a capitalist, seeking a profitable investment for his money, could not have derived much information from the opinions that had been expressed. The statements were so much at variance that it was almost impossible to form any opinion whatever. According to Mr. Wilson, works which must have cost a great deal did not appear to have had that consideration given to them which they deserved. It had been said that, anterior to the British rule in India, there were fourteen irrigated districts in Madras, as many as forty-three thousand tanks and channels in good condition, besides ten thousand out of order. The Government, it appeared, had allowed all these to fall into decay without replacing them, though no circumstances had occurred, by change of population or otherwise, to deprive them of their value. It was also said that about £4,000,000 had been expended, during a long course of years, on the irrigation of 4,000,000 acres. The revenue derived from them had been apparently at the rate of about 15s. per acre per annum, or an income of 75 per cent.; but where that profit went to was not mentioned. It had been stated that the natives had their own ideas, and did not always like the Englishman's practice of forcing his own upon them. It appeared from Mr. Wilson's statement that the unirrigated land produced crops worth only about one-third of those on the irrigated land. It would seem that 2,000,000 acres of irrigated land produced a revenue of £1,500,000 as against 25,000,000 acres of unirrigated land producing a revenue of under £2,000,000. The cultivator, therefore, when his land was irrigated, paid something like ten times as much revenue to the Government, whilst he got only three times as much crop.

Mr. J. A. Longridge regretted that so much time had been spent upon the question whether the Government or a company should carry out the works under discussion, and whether they were beneficial or not. He strongly objected to the idea which had been so broadly stated, that commercial success was the chief criterion by which an engineer was to be judged. It might be true that the pecuniary success of an engineer depended upon the commercial success of the works he carried out, but commercial success had nothing to do with the engineering ability displayed in carrying out the work. He might instance the finest works of engineering skill which this century had produced, the Thames Tunnel, the 'Great Eastern' steam-ship, and the Britannia Bridge, none of which had been commercially successful.

Mr. Beardmore protested against the argument just put forward. If the paramount necessity for commercial success were

disclaimed, it amounted to this, that a paternal government could, in this instance, get everything perfect if unlimited capital were devoted to every acre of the arid and boundless plains of the Indian empire; whereas the laws of the supply both of capital and labour were as definite, and, within limits, as fixed as the elements themselves. In this case millions of acres and millions of people were involved, and commercial success was absolutely necessary, because one of the most abundant elements had to be brought a great distance in the cheapest form to the soil, which from want of moisture was well fitted to receive irrigation. If a population had to be fed, and the revenue of its proper district would not reach the requirements, there was an end of the whole question. For in such a climate as India if famine prices were to obtain, the case became one of life and death. The advantages of irrigation and canal works were well exhibited by Mr. Login, who showed that in the year 1865-66 the price of corn at Meerut, on the line of the Ganges Canal, was £1. 4*s.* the English quarter, while away from the canal at Benares it was £2. 7*s.* The term Ganges Canal scarcely conveyed to English ears an idea of the magnitude of the work; it should be rather called the New Ganges high level river, as its volume was about equal to that of the River Thames at Kingston when flooded 2 or 3 feet above the summer level. One of the most difficult engineering points had been to construct suitable falls, which were necessary because the level of the country descended more rapidly than that of the canal. An immense volume of water had to be carried by a channel which, for economic purposes, was limited in size. Then also for the same reason the falls had been too much concentrated;—more so than if there had not been a wish to limit the cost of the works; and from this it followed that, after the canal had been completed and opened, it was found necessary to provide space for the tailing up of the water at the foot of the fall, so as to break the direct blow, as in an ordinary river weir where there was always a weir-pool. If the falls of the River Thames between Oxford and London were concentrated at a few large weirs, instead of being distributed over several of small dimensions, they would have been far more likely to cause damage during floods. In the present case, the weirs were adapted for a large volume of water that should have been penned up to give less velocity of current by greater sectional area; under these circumstances there appeared to have been an abrasion of the soil at several places to a dangerous extent. And so it had been with the Middle Level Sluice; the water came through the sluice with a fall, holes were eroded, and well-known difficulties arose, which he thought might have been obviated by a few barge loads of stone. In a similar case, he had been obliged to keep a stock of rough stone ready to

throw in at the foot of the sluice after heavy floods so long as seventeen years after its completion; and even after that period nothing but constant care prevented a casualty. From these cases it might be gathered that, with an enormous artificial river, such as the Ganges Canal, carried through a treacherous soil, repairs were of paramount necessity for years after its completion. It was necessary also in the design to multiply the falls, to effect a reduction of the velocity of the current and prevent an undue enlargement of the sectional area. One difficulty arose from the large quantities of silt carried in the water of the canal from the Himalayas; this could only be deposited in the bed of the canal or its branches, and might prove too abundant to be dealt with in any way but by manual labour during an annual closing of the canal. It appeared that the waters of the River Ganges were, for six months in the year, derived principally from the melting snow in the Himalayas, and were heavily charged with silt; while the rivers in the Madras Presidency were comparatively clear, being fed by the monsoon rains falling upon harder rocks. But any accurate information upon these points would be of great service to hydraulic engineers, more especially to those in India. There was a marked distinction between the Madras irrigation-works and those of Upper India, inasmuch as the former were at the head of the deltas, and the water was led off into a vast extent of flat land with ancient channels and other provisions for irrigation situate below the surface of the river from which the water was supplied. In the case, however, of the canal taken from the Ganges, there was a new country to be watered, new irrigation channels to be provided, under circumstances certainly not so favourable to their construction above the level of the ground, one of the points where the Madras works were alleged to be superior. There were other circumstances which must necessarily establish important distinctions between works carried out in countries so distinct; and it was evident that no opinion could be formed upon one from the circumstances of the other. With regard to the experiments made by Mr. Login at the Solani aqueduct, he had himself made certain experiments some years ago, which confirmed the idea that with an increase of hydraulic mean depth a more regular flow of water was produced; and on this principle it was undoubted that large pipes and sewers would permit the use of a larger coefficient in the formula for the calculation of their discharge.

Mr. Hawkshaw, Past President, observed, that an opinion had been expressed that the deposition of a few boat-loads of stones would have prevented the disaster to the Middle Level Sluice; but he thought they would have been of no use in arresting that catastrophe.

Mr. J. T. Harrison observed, that during the last forty years

engineering, as connected with canals, rivers, and navigation, had been considered as comparatively less important than it was previous to that date. But at the present time it appeared to be one of the principal objects to which the attention of engineers would be directed. The canals and system of irrigation under discussion were very different in character. In the Madras Presidency the water which flowed from the hills was in some cases collected in large reservoirs, and whatever sediment it contained fell to the bottom, so that the water was drawn off in a clear condition. In others, long weirs were thrown across rivers near their delta, and care was taken to prevent the water passing into the irrigation channels during floods, so that no silt or sand should be carried with it. On the Henares Canal in Spain precautions were also taken to prevent the passage of silt and sand into the canal; but on the Ganges Canal the case was quite different. The Ganges Canal derived its water in great measure from the melting of snow upon the Himalayas, and during the summer season when water was most required for irrigation, it came down in an extremely muddy state, carrying with it also a large quantity of sand.

He would not enter upon the question of the construction of the embankments for the reservoirs in Madras; but, as compared with the English system of reservoir embankments with puddle banks, there were striking differences which it might be well to notice. He would rather draw attention to the means by which the water was diverted from the rivers into the irrigation canals or channels. In this respect the three cases differed very much. At the head of the deltas in Madras the rivers were very wide, sometimes 2 or 3 miles, and comparatively shallow, with a sandy bed. The weirs were of simple construction, and not nearly so strong as they were usually built in this country. The River Henares was comparatively narrow, with a considerable fall, and the foundation, instead of being silt or sand, was strong, firm clay rock. In this case good substantial weirs had been erected across the river for the purpose of diverting the stream. In the Ganges the fall was probably much the same as on the Henares, about 11 feet or 12 feet per mile; but at the point where the water was diverted, there was a large area of shingle, with numerous channels passing through it. The construction of any solid work across the River Ganges would be one of considerable expense, and might be of doubtful result, and temporary weirs were consequently adopted. The structure of these weirs was of a simple character, and it might be interesting to explain it. The work was carried on by means of a barge attached to a strong hawser, stretched across the river, and firmly fixed at both ends. On this barge a derrick and windlass were fitted up, and by these the materials were lowered into position. Triangular frames formed of poles about 18 feet long, firmly spiked together

were placed vertically, with the apex down-stream, about 15 feet apart. The poles lying on the bed of the river were crossed by rough poles, and boulder-stones were thrown upon them; by these they were kept in place. Again poles were spiked across the upper part of the frames, and the whole was filled with boulders. The water was thus dammed back, though a great deal escaped, and the difference of level between the water on the upper and the lower sides of the weir was about 3 feet; the depth of water being about 12 feet above the weir, and 9 feet below it. At a short distance lower down a similar weir was erected, and then a third. After the third weir was completed, the water was so effectually diverted, that an active person could leap from stone to stone across the river without getting wet: at two other points similar weirs were erected. For about £2,000 these temporary weirs were constructed every year across the Ganges, and effectually diverted the water into the irrigation channel, or Ganges Canal. A permanent work would cost about £80,000 at the lowest estimate, as against £40,000, representing twenty years' purchase of these temporary weirs which were swept away annually by the floods. It was questionable whether a permanent weir would succeed, whether the weir itself might not be destroyed, or the channels of the river mischievously altered in direction.

The next point to be considered was the proper inclination to be given to the channel. In the Madras Presidency the canals had only to carry comparatively pure water, so it was quite possible to work them satisfactorily with the same inclination as the New River, or about 5 inches or 6 inches in the mile. That inclination would not, however, answer for the Ganges Canal, carrying a large quantity of silt. The quantity of sand excavated from the distribution channels of the Ganges Canal amounted to about 2,000,000 cubic yards per annum, at the cost of about one penny per cubic yard, so that, without a proper inclination, the Ganges Canal would soon silt up, and the expense of removing the silt would become a serious charge. In the Henares Canal he believed the inclination was about 11·03 inches per mile. The object of this inclination was to avoid the annoyance of the growth of weeds by increasing the velocity of the stream. The Thames in some parts afforded an excellent illustration of the importance of maintaining sufficient inclination and velocity to enable a river to carry off mud. He had found that for several miles above Oxford the natural fall of the Thames valley was about 14 inches in the mile, the minimum inclination at which, apparently, in this country as in India, large rivers could carry off mud. The River Thames formed a winding channel through this valley of deposited mud; by the introduction of locks, the inclination was reduced from 14 inches to 11 inches per mile; consequently a considerable part of the Thames above Oxford was silted up, so

that a boat drawing 18 inches of water could not pass up the river. The extensive floods at Oxford were in great measure occasioned by the introduction of locks and dams, which reduced the inclination from 31·2 inches to 7·5 inches per mile. Those works were executed towards the end of last century, and could not be considered as any disgrace to the engineers, considering the circumstances under which they were carried out. The engineers reported on what should be done with the Thames, but the works were executed by local persons, who, in fixing the sills of the locks, did not act upon the recommendations of the engineers.

Before works were undertaken, and water for irrigation was delivered from the canal for distribution over the land, it would become an important question to consider the value of it. Upon this point the Papers give useful information. It was found that the value of water for irrigation varied greatly. In Madras the value of a ton of water was about $\frac{1}{11}$th of a penny, whereas in the Ganges Canal it was about $\frac{1}{60}$th of a penny; and in the Henares and Esla Canals the cost was respectively about $\frac{1}{10}$th and $\frac{1}{13}$th of a penny. In the Lorca Canal it rose as high as $\frac{6}{10}$ths of a penny per ton, whereas in Lombardy it was only $\frac{1}{240}$th of a penny per ton.

Another important point for the engineer to attend to was the volume of water required at different times of the year and for different crops. It had been contended that an engineer had nothing to do with agriculture; but, in his opinion, the engineer must go into details, and master facts on agriculture as on other subjects, in order to be able to give satisfactory recommendations to those who employed him. It would appear that in Madras and in Northern India the quantity of water required to grow a wheat crop was about 1,000 tons per acre per annum, and in Spain 3,600 tons; for rice, about 2,600 tons were required in Madras, and on the Ganges 2,500 tons, whereas in Spain 18.000 tons were required per acre per annum. It was a singular fact that the quantity of water passed on to the land was much greater than these figures indicated. In Madras there would appear to be about 14,000,000 acres irrigated, and 13.200 tons of water per acre passed on to the land: in the year of famine the quantity delivered from the Ganges Canal was about 12,000 tons per acre, or about ten times the quantity required in ordinary cultivation under proper conservancy. On the Henares Canal the volume of water was about 5,000 tons per acre; but at Lorca, where the price was $\frac{6}{10}$ths of a penny per ton, the quantity was only about 220 tons per acre per annum. In conclusion, he exhibited a Table of statistics of irrigation in Madras, Upper India, Spain, and Italy; and a Table of statistics of irrigation canals:—

STATISTICS of IRRIGATION in MADRAS, UPPER INDIA, SPAIN, and ITALY.

INDIA.

Name of Country.	Area Irrigated.	Charge for Water per Ton.	Value of Land or Crop. Before Irrigation.	Value of Land or Crop. After Irrigation.	Supply of Water per Acre. Wheat, Oats, &c.	Rice.	Sugar.	Average Supply per Acre.	Remarks.
	Acres.	*d.*			Tons.	Tons.	Tons.	Tons.	
Madras									
In fourteen Districts .	2,000,000		Crop						
Altogether .	4,000,000	$\frac{1}{11}$	12*s.*	40*s.* threefold.	980	2,636	6,030	13,200	
Ganges Canal in 1860	343,000	$\frac{1}{65}$	Sugar 50*s.*	300*s.* sixfold.	1,000	2,500	5,000	12,000	The famine year.
Do. at present	960,000	..	Land 1	to 10 tenfold.					

SPAIN.

Name of Country.	Area Irrigated.	Charge for Water per Ton.	Value of Land or Crop. Before Irrigation.	Value of Land or Crop. After Irrigation.	Supply of Water per Acre. Wheat, Oats, &c.	Rice.	Sugar.	Average Supply per Acre.	Remarks.
Henares Canal . .	27,170	$\frac{1}{10}$	Land £. 6 to 8	£. 80 to 120 twelve to fifteenfold.	Average of other crops than rice 3,620	18,100	..	5,000	Sum expended £200,000, or £7. 7*s.* per Annum.
Esla Canal .	32,140	$\frac{1}{13}$			..	..	..	..	Sum expended £100,000, or £3. 2*s.* per Annum.
Lorca . .	..	$\frac{6}{10}$	..	..	..	..	..	222	Water very scarce.
Mean of five Canals .	..	..	..	..	..	..	..	6,226	
By large Districts .	340,000								
By Water-wheels and small Canals . .	1,879,500								
Total .	2,219,500								

ITALY.

Name of Country.	Area Irrigated.	Charge for Water per Ton.	Value of Land or Crop. Before Irrigation.	Value of Land or Crop. After Irrigation.	Supply of Water per Acre. Wheat, Oats, &c.	Rice.	Sugar.	Average Supply per Acre.	Remarks.
Piedmont & Lombardy	..	$\frac{1}{243}$							

ENGLAND.

Name of Country.	Area Irrigated.	Charge for Water per Ton.	Value of Land or Crop.		Supply of Water per Acre.			Average Supply per Acre.	Remarks.
			Before Irrigation.	After Irrigation.	Wheat, Oats, &c.	Rice.	Sugar.		
	Acres.	*d.*			Tons.	Tons.	Tons.	Tons.	
Barking Farm	..	..	..	..	..	..	..	5,360	London Sewage.
Croydon Bluid Common . .	..	..	..	..	..	..	..	6,000	Sewage.

QUALITY OF WATER.

INDIA—MADRAS.

River Water produces two and a quarter times as much as Spring Water.

ENGLAND—DORSETSHIRE.

Spring Water sometimes very valuable.

TEMPERATURE.

Barking experiments show—gross growth proportional to temperature.

EVAPORATION.

	Inches.	Tons.	
Red Hills, near Madras, in April, May, June, July, and August	= 56	= 5,600	per acre per ann.
Madrid, ditto, ditto	= $46\frac{3}{4}$	= 4,675	„ „
London, average annual from water surface .	= 36	= 3,600	„ „

SAND CARRIED BY GANGES CANAL.

50,000,000 cubic feet = nearly 2,000,000 cubic yards per annum.
The removal of which costs about £8,750 per annum.
Equal to about 1*d.* per cubic yard.

STATISTICS OF IRRIGATION CANALS.

INDIA.

Name of River or Canal.	Length of Canal in Miles.	Fall per Mile.	Velocity.		Discharge per Day in Gallons.	Remarks.
			Feet per Second.	Miles per Hour		
		inches.				
Ganges Canal :—						
To Nanoon . . .	180					Total cost £2,000,000
Cawnpore Branch .	170	14	3·75	2·2	2,700,000,000	Weir temporary — costs £2,000 per an.
Etawah	180					Weir permanent would cost £80,000.
	..	17	..	3·0	.. ..	Dangerous cutting bed
Ditto	..	15	..	$2\frac{3}{4}$	.. ..	Slightly ditto.
	..	13·8	..	$2\frac{1}{4}$	.. ..	Silting up.
Madras	..	12	..	..	.. ..	Channel 25 ft. × 3 ft
Godavery Kistnah .	..	5 or 6				

SPAIN.

Name of River or Canal.	Length of Canal in Miles.	Fall per Mile.	Velocity.		Discharge per Day in Gallons.	Remarks.
			Feet per Second.	Miles per Hour.		
		inches.				
Henares River . .	36	11·3	..	..	75,600,000 to 4,320,000,000	Weir 130 yards long —cost £17,343.
Ditto Canal . . .	28	..	2·4	1·6	.. ..	Depth of water 5 ft.
Esla Canal . . .	..	..	..	..	.. ..	Weir 191 yards long —cost
Many Old Canals .	..	..	3·0	2·0		
Marseilles Canal . .	51	29	2·86	..	212,889,600	Query weirs?

ENGLAND.

New River . . .	28	6	..	0·4		
London Main Sewer .	..	..	..	1·5	.. ..	Sufficient to keep sewers clean.
Thames :—						
Rushey to Godstow	18½	14	..	..	.. ..	Reduced to 11 inches per mile by locks.
Godstow to Sandford	7⅛	31·2	..	..	.. ..	Reduced to 7·5 ins. per mile by locks. 4 ft. fall at Sandford when meadows flooded.
Tyne	..	600	..	..	.. ..	At Haltwhistle 50 ft. per mile, carrying large boulder stones.
Severn :—						
Stourport & Diglis (near Worcester)	14	19·75	Natural Fall.			Flood rise sometimes 18 feet in 5 hours, and sometimes 2 ft. above low water.
Diglis to Tewkesbury	16	4·7				
Tewkesbury to Gloucester . . .	10	2·0				

Mr. LOGIN, in reply upon the discussion, observed that the slope of the Ganges Canal was originally projected at 15 inches in the mile, and the calculated velocity of the current at 4 feet per second. In the year 1860, when he took charge of the works, the surface-slope exceeded 16 inches, with a mean velocity of $4\frac{1}{2}$ feet a second, and the bed was being eroded to a dangerouse extent; this he had reduced to about 14 inches in the mile, and the mean velocity of the stream had fallen to $3\frac{3}{4}$ feet in a second. With this reduced velocity the bed began to silt up, and it had continued doing so for the last five years; therefore he believed the proper slope and velocity had been attained. Although the difference in the velocity of a stream, when pure and when charged with silt, was not appreciable where the slope of the ground was flat, yet as,

after a heavy fall of rain, the thick muddy water was evidently retarded in running down a steep slope, he concluded that the celerity of a river must, in some degree, be lessened when bearing silt. Where rivers had to be bridged over, the velocity was not of much moment so long as it was not increased. It was only when additional local celerity was produced, by bridge-piers or other obstructions, that erosion of the bed could ensue. He had measured a torrent with the water highly impregnated with silt, and although it rushed through a bridge at the rate of 7½ feet per second, there was no apparent action on the river bed, which was of pure sand. In reference to Mr. Beardmore's remarks, he might say that hundreds of thousands of feet of boulders and all the vitrified bricks that could be procured from the brick-kilns had been thrown below the weirs. He had recently inspected some of the tumbling-bays on the River Lee, and observed that on a small scale the same action had taken place as at the Ganges Canal falls, and that the remedial measures adopted on the River Lee were identical with those that had proved so effective on the Ganges Canal. He thought the question of slope a very important one, as it determined the proper point for the head of the canal. If it had been at Sukertal it would not have been possible, with a slope of even 12 inches per mile, to irrigate the Doab, as the water could only reach the surface somewhere in the Cawnpore district: and had the canal-bed a slope of only 4 inches per mile, as proposed by Sir Arthur Cotton, he believed it would have silted up just as the Thames had silted up, as described by Mr. Harrison.

Mr. Allan Wilson, in reply upon the discussion, remarked that there were already many comparatively small works of irrigation in Southern India. As had been pointed out, all the valleys of Southern India, through which flowed little rills of water, were dammed up in so many places that not one drop was allowed to escape into the larger rivers. These small reservoirs were not in all cases used directly for purposes of irrigation; but they frequently supplied the village wells with water during the hot season. Their maintenance was of vital importance to the villagers, as enabling them to preserve the lives of their cattle, failing which the land must remain fallow and the inhabitants be subjected to the horrors of famine.

The great want in regard to irrigation in India was a means of turning to account the rivers, many of which at present flowed into the sea, unfettered by any artificial dam, although it was fully recognised by those who were acquainted with India, that great facilities existed throughout the country for constructing artificial reservoirs and damming up rivers. As an illustration he might draw attention to the sketch of a dam (Plate 20, fig. 3) which, it was estimated, would store up water sufficient to irrigate 200,000 acres

of land; and yet the width of the gorge across which the dam was to be constructed did not exceed 350 yards. Many sites for irrigation works, even more favourable than the above, might be selected in various parts of India; and it was a matter of surprise that such great natural advantages had not long since been turned to account. He had been placed by the Government of India in charge of the Raichore Doab, where irrigation was largely carried out, and thus had peculiar facilities for examining the different systems of cultivation by means of irrigation in Southern India. Having mixed freely with the people, and obtained their confidence, he had no hesitation in stating that all the land that could be brought under irrigation in that locality would be eagerly taken up by the ryots directly the water was ready to be laid on. The necessity of carrying out these works on a more extensive scale than hitherto was now fully recognised both by Government and the public. According to his judgment it was mainly by means of private enterprise, by taking advantage of the large capital of this country which was always obtainable when profitable investments were presented, and by bringing the skill and scientific knowledge of English engineers to bear on the question, that a comprehensive system of irrigation in India could be carried out, with the rapidity which was essential to meet the requirements of the people and country. He therefore thought the requisite capital should be raised by private companies, and that the works should be carried on by engineers specially selected by the companies.

He was aware that the defective mode in which some of the works confided to private companies had been carried out, the slow progress of others, the excess over the estimated outlay, and the general unsatisfactory results, both as regarded profits to Government and the shareholders, and benefit to the people and country, had not unnaturally led to the idea that the system of executing public works by means of private enterprise was not adapted to meet the requirements of India. Nevertheless he was convinced that these defects were not inherent in the constitution of companies formed for constructing irrigation works; and it must be borne in mind that the system of executing public works by this agency had only been partially tried, and under imperfect conditions that had unavoidably led to failure. He was of opinion that these evils might be entirely obviated by means of a proper understanding between the Government and the Company, so as to make the conditions mutually advantageous.

He had drawn up a project for carrying out irrigation works through private companies, but the details were too minute and lengthy to be fully explained on the present occasion; he might, however, briefly sketch the principal conditions he suggested for the construction of irrigation works. He would propose the formation

of a company with sufficient capital which should only be called up as required. The cost of each work, and the period within which it was to be completed, should be agreed upon beforehand between the Government and the Company. The nature and extent of irrigation should be settled, and the rate per acre at which water could be supplied, as well as the extent of land to be irrigated, should be agreed on. A moderate rate of interest should be guaranteed by Government during the construction of the works; and the amount expended on the works should be repaid to the Company by means of an annuity, terminable within a fixed number of years, so as to render the burden on the finances of India as light as possible. He proposed to frame the condition between the Government and the Company in such a manner as to give both parties an equal interest in the efficient and speedy construction of the works. This interest had hitherto been entirely wanting in the arrangements made between Government and private companies for the construction of public works of various kinds; and it was to this want that the partial failure of agreements might to a great extent be attributed. He entirely concurred in the opinion that the control and administration of all public works in India should rest with the Government, and he had accordingly provided for each work, or portion of a work, being handed over to Government as soon as completed; and he would suggest that its rateable value should immediately be credited to the Company, less the amount of interest paid, such sum to be paid off by terminable annuities extending over a long period of years. Also that, in order to give all the chief officers of the Company a direct interest in carrying on the works to a speedy and successful termination, the remuneration from the Company should be made dependent on the prompt, efficient, and economical construction of the works. These were the main features of his project for completing works, which he had submitted as a whole to the Secretary of State for India. At the same time he had made definite propositions for undertaking the construction of particular works in various localities, and for handing them over to Government complete and in working order within fixed periods.

Mr. W. H. Delano remarked, through the Secretary, that the 'barrage' of the Nile by the French, which had cost £4,000,000, was a failure. He had seen clover cut fifteen times in a season on irrigated land in Egypt. The water in the canals of the delta was quite limpid, even during the inundation, when the river was muddy; and this confirmed Mr. Login's observations, and showed that the Nile water fertilized, and not the Nile mud only.

Mr. G. H. Phipps remarked, through the Secretary, that

whatever connection might exist between the political aspects of this question, either in respect to the action of Government or that of private companies, and the executive portion to be carried out by the engineer, it was evident that in proportion to the economy with which such works could be efficiently constructed would be the inducement either to Government or to companies to carry them into effect: to the former as requiring a smaller imposition of taxes on the people to be benefited, and to the latter the division of a larger profit. It was then to the engineering portion of the question that he would refer. In laying out such a work as the Ganges Canal, one of the most important considerations was evidently the inclination proper to be given to the surface of the canal, as upon that depended so largely the area of land which could be irrigated. The profile course of a river, having its rise amongst mountains and gradually flowing into the plains beneath, described a curve, concave to the horizon throughout, but more inclined near its source than elsewhere; and as it occupied the lowest line in the valley through which it flowed, the high land on each side was of course entirely cut off from irrigation by means of the natural river. The longitudinal profile of the irrigation canal, leading out of such a river should be, as near as circumstances would permit, a regular inclined plane, whereby the altitude above the bottom of the valley was everywhere increased, except at the extremities; and the lateral higher lands correspondingly governed. It was evident that the steeper the inclination which could be allowed for the surface of the canal, (while starting from some fixed level on the lower part of the river,) the higher would be the point reached towards its source, and the greater the area of land placed under command for purposes of irrigation. Thus much was necessary to be mentioned, prior to remarking upon the considerable variation of opinion exhibited in the present Papers, where one authority appeared to consider an inclination of 4 inches to 6 inches in a mile sufficient, whilst another stated that from 12 inches to 14 inches in a mile was found practically not too great, while all were agreed that where the inclination was too slight the growth of weeds and deposit of silt were promoted, that where too steep the bottom and banks of the canal were scoured and sometimes the adjoining lands covered with sand. On this question Mr. Login had observed that a stream of water carrying with it a large amount of matter in suspension might safely have a greater inclination than could be allowed if it conveyed pure water. He had hoped to have been able to find some solution for this, but had not succeeded.

In making a calculation to elucidate this, the following data were required:—

1. Inclination of surface of river = 1 in 5,000
2. Depth of water in river = 8 feet
3. Speed per second = 4 feet
4. Proportionate bulk of silt to water = 1 in 1,700
5. Specific gravity of silt = 2
6. Speed at which silt would settle imperfectly in still water } = 6 inches per minute.

The three first of the above were approximate data derived from the Papers on the Ganges Canal: the next two from observations by Mr. Login on the river Irrowaddy when in flood, and the last from experiments for that purpose referred to by him.

Fig. 2.

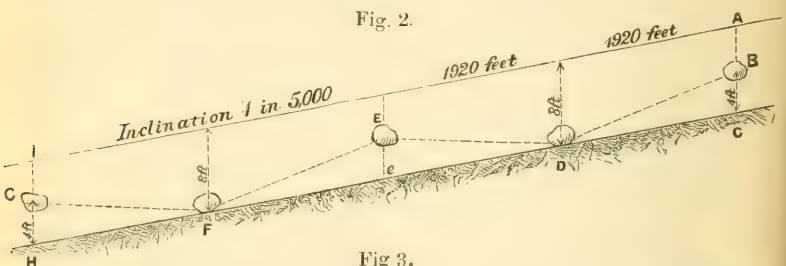
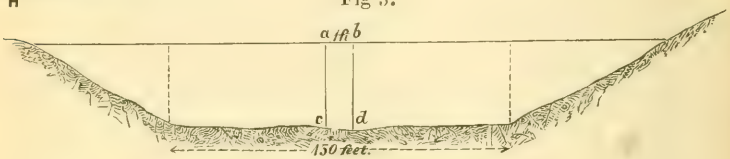


Fig 3.



Let Fig. 2 represent a longitudinal section of a portion of the canal 1 foot in width (*a b d c*, Fig. 3), in which B represented all the foreign matter entering the canal in a given time on the section A C, situated at its centre of gravity B; and assume that in equal times the body B sank to D and was forced upwards to E, and so on; then the difference of specific gravity of B and water, equal in this case to 1, would give B × E *e* the power required to sustain the silt. The power spent in moving the water, calling W the weight of water passing A C, in the same time, would be $\frac{W \times 3840}{5000}$; but B was only $\frac{1}{1700}$th of W, and therefore the proportion of the power to sustain the silt compared with that to move the water would be as $\frac{W \times E\,e}{1700} : \frac{W \times 3840}{5000}$, or finally as $\frac{4}{1700} : \frac{3840}{5000}$, or as 1 to 326. Thus if the above calculation

were taken as an approximation only to the truth, the proportion of power required to keep the matter in suspension, compared with the power required to move the water, would be only as 1 to 326, and nearly all the power due to the inclination for producing impacts upon the bottom would be left.

Without throwing the slightest doubt on the facts considered to have been observed by Mr. Login, as to the difference in scouring power of pure and silty water, he thought it would be unsafe to admit it as a confirmed principle in hydraulics, but he would be more inclined to attribute the facts observed to some compensating influences where the erosion at one time might be balanced by silting up at another.

Mr. E. B. Webb stated, through the Secretary, that the expectation of ultimate profit ought to be the basis of irrigation enterprises. Although it was true that they had often, if not generally, resulted in a loss to those who paid for them, yet the fault had not been an inherent one; such works ought to be amongst the most profitable in the world. One mistake had almost always been made; plans were elaborated, companies formed, and works executed before any binding agreement had been made with the landowners to take the water, and the companies were then left to their mercy. In all irrigation works upon which he was now engaged, the landed proprietors, after the plans and estimates had been completed, had bound themselves to take a certain quantity of water at a certain price, and gave first mortgages upon their estates as security.

In reference to the quantity of water required for irrigation, the attempt to apply a general rule would appear absurd to any one who had seen irrigation carried out in various climates on various soils and for various crops. It would be absurd to assign the same quantity of water for the growth of plants upon clay soils in a temperate climate, as for that of sugar-canes on a sandy soil in the tropics. The engineer should endeavour to obtain the most abundant supply possible under the conditions of source of water and amount of funds. He should study the character of the soil to be irrigated, the climate, and the crops to be produced. Probably local experience would afford data for estimating the minimum quantity of water required to produce a sufficiently beneficial result to pay for the expenses incurred; for it generally happened that where it was found worth while to attempt irrigation on a large scale, small irrigations would be found to have been previously carried on. It should be borne in mind that in a dry climate, and with ordinary crops, even a small amount of water would be beneficial in certain seasons. The application of a ton of water in one season would produce double or treble the effect of a similar application in a less arid season; and it was, therefore, futile to attempt

to apply a general rule for the quantities of water required in irrigation works.

Mr. W. Atkinson remarked, through the Secretary, that the principal dimensions and other particulars of the most remarkable weirs in Spain would be found in the annexed Table.

[See Table opposite.]

April 28, 1868.

CHARLES HUTTON GREGORY, President, in the Chair.

The discussion upon the Papers Nos. 1,193, 1,200, and 1,204, on "Irrigation in India," and on "Irrigation in Spain," was continued throughout the evening, to the exclusion of any other subject.

The following communication from the Council was brought forward, was adopted by acclamation, and a copy ordered to be sent to Mr. Whitworth:—

"Attention having been called to the foundation, in perpetuity, by Mr. Joseph Whitworth, M. Inst. C.E., of Thirty Scholarships, of the annual value of £100 each, for the instruction of young men, natives of the United Kingdom, to be selected by open competition for their intelligence and proficiency in the theory and practice of mechanics and the cognate sciences, with a view to the promotion of engineering and mechanical industry in this country, it was

> "Resolved unanimously,—That this Meeting desires to record, on its own behalf, and on that of the members of all classes of The Institution of Civil Engineers, its grateful recognition of this act of munificence, and its high appreciation of the services which have thereby been rendered to the cause of technical education and national advancement, and of the advantages that may be expected to accrue, alike to the profession and to the community generally."

To face page 552.

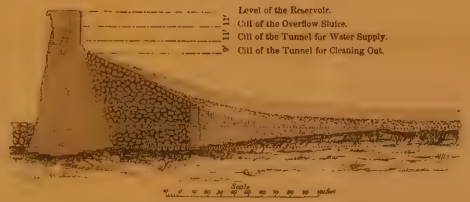
TABLE of the PRINCIPAL DIMENSIONS and other particulars of some of the most remarkable WEIRS in SPAIN.

Name of the Weir.	River.	Top of the Weir. Form.	Length. English feet.	Height. English feet.	Thickness of the Weir. Bottom. English feet.	Top. English feet.	Side of Weir next to the Reservoir.	Means for regulating the height of Water.	Conduits which pass through the Masonry.	Materials used.	Year when commenced.	Observations.
De Tibi, or of Alicante.	Gorge formed by the mountains Mos del Bou and Crezta.	Arc of circle chord 210 feet and versed sine of 9 feet.	220	146	110	64	Almost vertical.	Overflow at the right and top of weir.	A spacious gallery at the bottom of the wall for getting out the mud, and a tunnel for running off the water.	The back and front are of dressed ashlar, with rubble in mortar in the interior; the whole rests on the rocks of the mountains.	1579	Finished in 1594. In 1697 a considerable opening appeared, which was built up in 1798, since which time no alteration has taken place. The water for irrigation flows through a tunnel in the rock.
De Puentes	Lorca, at the meeting of the Velez and Luchena.	Triangle, the sides being 261, 381, and 148 feet in length.	790	164	132	20	Vertical .	In place of the sluices, which could not be opened when the weir was in danger, an overflow of 28 feet was constructed to the right, but it was inefficient.	An arch 22 feet span for cleaning out mud, and a tunnel of 5 feet with flood-gates.	Ashlar with 3 feet headers in the front and back, well dressed on the face, but with bad beds and joints. The interior of concrete of round stones. Built on piles.	1785	This weir, owing to its bad construction, had little resistance, and soon after the filling of the reservoir its weakness became apparent, and no efficient means being taken to avoid its destruction, this took place on the 30th April, 1802, causing great devastation.
Del Gasco	Guadarrama .	Straight. . .	820	305	238	14	Slope of 60°	Overflow of 55 feet on the right.	An arch of 28 feet in the bed of the river, which should not be considered as a permanent work, but as an aid to construction.	Rubble, 9 feet thick throughout the back and front, then cross-walls uniting them, leaving spaces which were filled with stone and clay.	1788	On the 14th May, 1799, when the work had reached a height of 188 feet, the rain produced an increase in the bulk of the filling, and part of the interior wall gave way, and the work was stopped.
De Valdo Infierno.	Luchena . .	Regular pentagon, the sides being each 52 feet in length.	260	117	164	28	Vertical .	No overflow	An opening of 11 feet for cleaning out. An upper tunnel of 3 feet, and a lower one of 5 feet.	Like the weir of Puentes, only the headers were longer. Built upon steps in the oolitic limestone as laid bare by the river Luchena.	1792	It is 16 feet less than the total height intended. Notwithstanding the apparent strength of this work, its existence has depended upon care being taken not to fill the reservoir with water, and 45 feet of the bottom has been filled in with earth from the adjacent sides.
De Nigar	Rambla del Canizal.	Arc of circle 104 feet chord and 10 feet versed sine.	345	91	68	55	Almost vertical.	There is no account given of any overflow at the sides; the level of the water is probably regulated by the conduits through the weir.	An opening of 3½ feet for cleaning out. An opening of 2½ feet for irrigation. A well for sluice-gates of 3 feet, and a well 9 feet diameter.	Ashlar front and back, with rubble filling.	1850	The resistance depends upon the density of the mass and its arched form.
Ponton de la Oliva. (Figs. 4 & 5.)	Lozoya . . .	Straight . . .	235	105	126	22	Slope of 30°	Overflow, independent of the weir, constructed in the rock at the left, 27 feet wide and 11 feet below the top of weir.	No conduit passes through the weir. The water is taken through a tunnel in the rock at the right, and another tunnel below this is used for cleaning out.	Ashlar with long headers, dressed on the beds and joints with care; filled in with rubble. All the mortar is hydraulic. Built upon steps in the limestone rock.	1852	The mass of the weir is greatly superior to the resistance which has to be overcome. The slope of the interior causes the weight of the water to assist the stability of the weir. The rock in the river, in front of the weir, is so hard that the water falling over does not wash it away. The foundation being on level beds of rock, no movement can take place. The good workmanship and the excellent hydraulic mortar cause the stones to be so well united that no water can pass through.

MADRID WATER SUPPLY.—WEIR OF THE PONTON DE LA OLIVA.

Fig. 4.

Fig 5.


Level of the Reservoir.
Sill of the Overflow Sluice.
Sill of the Tunnel for Water Supply.
Sill of the Tunnel for Cleaning Out.
11' 11"

May 5, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected :—WILLIAM BAGE, FRANCIS BRADY, MAXIMILIAN HJORTSBERG, GEORGE WILLIAM VIVIAN, and JOHN WOOD, as Members; CHARLES DALLAS ALEXANDER, B.A., the Chevalier ZOSIMO BARROSO, EDWIN BIDDER, PETER BROTHERHOOD, JOÃO NERI FERREIRA, THOMAS GIBSON, JAMES HARTLEY, M.P., EDWARD JOHN JONES, HENRY AUGUSTIN ORNANO MACKENZIE, JOHN MILROY, Lieut. COLIN CAMPBELL SCOTT MONCRIEFF, R.E., Lieut. PATRICK MONTGOMERIE, R.E., WALTER NEILSON, SAMUEL BARTON NEWTON, RICHARD PROCTOR-SIMS, HORACE JAMES RYDON, and WILLIAM JOSHUA TREHEARNE, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :—JOHN SAVERY CAREY, HUMPHREY HENCHMAN, and JOHN ARTHUR OWEN.

The discussion upon the Papers Nos. 1,193, 1,200, and 1,204, on "Irrigation in India" and on "Irrigation in Spain," was continued throughout the evening, to the exclusion of any other subject.

May 12, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

No. 1,179.—"On Engineering Philosophy: The Durability of Materials." By EDWIN CLARK, M. Inst. C.E.

IT is no doubt a subject for congratulation, that the Engineer of the present day is generally too incessantly occupied to afford much time for theoretical discussion. The valuable Papers which each session adds to the Minutes of Proceedings of the Institution are characteristic of a practical epoch. They are mostly either descriptive of great and important engineering monuments, which will hereafter commemorate peaceful times, or they are records of the still more remarkable mechanical appliances by which human labour has been economized and civilization so strikingly advanced. It has indeed been truly observed, by one of the Past-Presidents, that the application of the Principles of Natural Philosophy to practical purposes is the essential province of the Engineer. There is, however, on the other hand, a possibility, that in taking its rank among kindred sciences, the too rigid application of the "cui bono" to Civil Engineering may not only detract from its dignity, but what is of far more importance, may narrow its scope and interest, and thus forfeit some portion of the invaluable support it has always hitherto received from that high and numerous class who love science solely for its own sake.

It is on these grounds that the Author ventures to hope that some interest would attach to a series of Papers devoted, not so much to the special application of those philosophical principles which form the basis of practice, as to the consideration of the principles themselves. It is by no means intended to attempt to lay down dogmatically any rules or formulæ with the stamp of authority; but numerous questions occur which could be more effectually discussed in their abstract capacity, than in connection with the practical applications out of which they arise. For instance, the general theory of strains, the durability of the materials of construction, the essential properties of girders, columns, and arches, the stability of foundations, the theory of heat as a mechanical power, the resistance of air and water to bodies in motion, or the laws of river and tidal action, may be cited as cases in point.

On all these, and on kindred subjects, the Engineer has arrived at well-established fundamental principles, capable abstractedly of being definitely recorded; while, on the other hand, they are all subjects requiring further elucidation, and affording elements for discussion of the highest interest. If the title should not appear too ambitious, the Author would suggest that a series of such essays might be appropriately called "Tracts on Engineering Philosophy."

In pursuance of these views, and in the hope of eliciting Papers on others of the subjects indicated, the Author will offer some general remarks on the Durability of Materials of Construction.

The list of materials used by the Engineer is but small. It includes stone and timber among natural productions, and bricks, cement, and the metals among artificial products. There is perhaps no better illustration of the difficulty of laying down any rigid rule in engineering, than the attempt to state, even approximately, the positive life of any of these articles. In certain situations it may indeed be estimated by geological periods. The most delicate fossils exist unchanged even in the oldest rocks; while, under other conditions, the hardest stone requires perpetual renewal. The durability of any material thus depends, not only on its own inherent properties, but principally on the agencies to which it is exposed.

As an example, the soft calcareous tufa blocks of the temples at Pæstum, not only as regards those parts of the structures that remain standing, but also as regards the ruins that lie half buried in the sand, present no appearance of decay, or even of great age; and yet their antiquity is so great, that Pliny, who wrote eighteen centuries ago, states that even then he was wholly unable to obtain any reliable record of their origin, on account of their great age. While far more evident symptoms of decay are apparent in the masonry of the New Houses of Parliament, not yet complete. Again, the ruins of the marble temples at Athens appear totally unaffected by time; the tool marks are still sharply defined, the colour is as unblemished as though just removed from the quarry—while here, the same material loses all its beauty in a few months; and the Marble Arch in Hyde Park shows far greater signs of age than the Temple of Minerva. In these cases the difference is due principally to the effects of climate. Other anomalies quite as remarkable are familiar to all. The telegraph wires on some lines seem unaffected by twenty years' exposure; while in other situations the total renewal of the wires becomes necessary every two or three years. This is again strikingly illustrated in the maintenance of submarine cables.

The varying durability of galvanized zinc roofs in different localities is similarly well known, and several kinds of timber, such

as beech, which under ordinary circumstances possesses no durable qualities, have been found sound after being buried for centuries in water. Nearly the whole of the buildings in Geneva, including the cathedral, are covered with ordinary sheets of tin; while at St. Petersburg the city is almost entirely roofed with extremely thin sheets of wrought iron, wholly unprotected by any coating, except occasionally a coat of paint; and yet these thin plates of tin and iron, which in the atmosphere of London would certainly be riddled with holes in a single winter, are there found to be extremely durable. The tin indeed retains its lustre through long periods of years, as every traveller must have observed on looking down, on a fine day, from the heights round about Geneva, when the city is almost as dazzling from its brightness as the lake itself. Again, the traveller cannot fail to be struck, with the extraordinary freedom from decomposition with which even animal matter seems in some situations to be endowed. The frozen carcass of the Siberian Mammoth was dug out of the ice perfectly unchanged, though its crystal tomb was probably of greater antiquity than any human monument, or even the human race itself; and without the protection afforded by frost, human bodies in the Morgue on St. Bernard, and generally in many of the houses of refuge on the high Alps, moulder away without any decomposition except desiccation, and lie unburied without inconvenience. The same phenomenon may be observed in many continental catacombs, as at Kief, in Russia, even without exposure to the air.

On examining all these facts, and seeking some common characteristic, it is found that among all these causes of decay, humidity holds the first rank, and it is to this subject that special attention will first be devoted. The decaying influence of humidity is evidently dependant on other coincident circumstances. The mere pressure of water, or even of a saturated atmosphere, is not sufficient to induce rapid decay, which appears to be caused by humidity only under peculiar conditions. One of these conditions is well known by the popular title of dampness. The decay caused by dampness, as in the case of dry rot, is as effectually arrested by the presence of water, as by a constant current of air, whether perfectly dry or saturated to any degree of humidity. Damp therefore is not the mere presence of moisture in the ordinary form in which it is held in solution by the atmosphere. If a hygrometer be placed in a damp situation, it simply indicates perfect saturation; no evaporation takes place, but the cotton covering of the wet bulb is speedily covered with a peculiar mould, well known by its fungus-like odour, and in a short time it is converted into an impalpable powder or ash. Under similar circumstances timber, leather, paper, and all like materials, undergo the same rapid decomposition; vegetable gums and oils, that are insoluble in water, and even

dry hard paints and varnish, become soluble and liquid. Massive timbers are rapidly disintegrated to the core, entirely losing their weight, though still retaining their form, and often totally free from apparent moisture, although at times dotted externally by drops of brilliant water. Damp spots are moreover peculiarly hygrometric, indicating atmospheric changes with remarkable precision; and temporary desiccation in no ways disturbs this process. The peculiar odour which always accompanies this condition is one of the best tests of its existence, and the expression that a room smells damp is strictly correct. The effects are, within certain limits, intensified by increase of temperature and absence of light, and arrested by poisons destructive to vegetable life. If this phenomenon of decay be more closely examined, the process will be found to resemble in many respects a slow combustion. The ultimate results of combustion and decay are strikingly similar; the union with oxygen is slowly effected, and the residue is more or less diluted with foreign substances, but whether bodies be burnt, or decayed, the remains in the ashes are substantially identical. Decay may thus, to a great extent, be looked upon as a decomposition resulting from the slow chemical combination of oxygen with the matters decomposed.

Now, if slow combustion be the cause of decay, and that particular state called dampness is so important an accessory, the inquiry naturally suggests itself, what connection exists between those agencies, or in what way can damp promote the absorption of oxygen? The Author can only presume to offer an opinion on this subject, with a view of eliciting correction from others more capable than himself of dealing with a problem to a great extent of a chemical nature. It cannot, however, be doubted, but that much light may be thrown on the subject, by the botanist as well as by the chemist. In the case of organic substances, the presence of vegetation in the form of fungus, or mould, is an invariable characteristic of decay, and the decomposing effect of all vegetable growth is beyond question. It will no doubt be remarked, that the vegetable growth alluded to may be the effect rather than the cause of decay. Doubtless the spores of these microscopic fungi follow the law of all other seeds, in vegetating only under those particular conditions of soil, light, and moisture which are adapted to their growth; dampness and partial darkness, and absolute quietude, and even decay, may be essential to their existence; and, therefore, it is only under such conditions that they appear at all. But, nevertheless, when they do appear, their presence rapidly accelerates the decay, and they furnish a vital medium, capable of accomplishing the observed effect — combustion, or slow union with oxygen, of the substances on which they thrive. It is probably by some such chemical vital action, that the fact can be

explained, that even the hardest rocks are rapidly decomposed by the growth of lichens, or that decay should be arrested by poisons which can exert no other influence than the prevention of vegetation. Such an assumption affords a probable explanation of the durability of masonry in a locality like Pæstum. The dry climate and perpetual sunlight of that sandy plain must prove an absolute bar to this class of vegetation; while the damp climate of this country covers every stone with a corrosive carpet of vegetable life. It is equally remarkable, that in the putrefaction, or rapid chemical decomposition, of animal and vegetable substances, the same profusion of the lower forms of animal, as well as vegetable, organisms characterises the phenomenon. Nature rejoices in perpetual youth. The sickly animal falls a rapid prey to the more robust. Fungi soon consume the hoary oak. Invisible myriads of animal and vegetable forms revel in the great transformation scene, engaged, it is true, in ceaseless destruction; but removing only the dead and useless, and ministering to the vigorous and strong.

Whatever may be the cause of decay, moisture is an indispensable element. Dry air is incapable of decomposition. Water is a carrier of oxygen in a potent form; and it is only from water, and more especially when in the form of vapour, that the oxygen necessary for decay can be obtained.

The non-decomposition of animal matter, under certain circumstances, even in hot climates, as already alluded to, arises solely from the absence of water. It might at first sight be imagined, that the moisture supplied from the animal tissues would alone induce decomposition. This, however, is more than counterbalanced, under such circumstances, by the rapid evaporation due to freedom from cloud, and the actual dryness of the air. In these cases, the absorbing force of the air more than counterbalances the decomposing chemical force, and putrefaction is arrested by the loss of the water necessary for the process. It is from the absence of moisture that the Mammoth has been preserved, without change, through ages of perpetual winter. The durability of tin and iron roofs in Geneva and St. Petersburg is due to the same cause; and the importance of some shelter for timber, and of thorough ventilation wherever it is employed in this moist climate, is a necessary corollary.

The durability of metals, like that of organized substances, depends, mainly, on the resistance they offer to combination with oxygen; and thus their decay may also be regarded as a slow combustion. But their durability further depends on the character of the oxides formed on their surface. Iron exposed to moisture is soon coated with rust, in the form of hydrated peroxides; and as these oxides do not adhere to the surface on which they are formed, additional flakes constantly form, and fall away, until the whole mass is destroyed.

As wrought iron is now so extensively used, its durability is a matter of special interest. In a pure dry atmosphere, it suffers, practically speaking, no deterioration whatever, in any lapse of time. It is also extremely durable in distilled water, free from air; but it is slowly oxidized in a moist atmosphere, and, with fatal rapidity, in air or water containing free acids or other corrosive agents. It is, however, efficiently protected from such agents by paint, which adheres to clean iron with great tenacity. It is also a remarkable fact, and not satisfactorily accounted for, that its oxidation appears to be to a great extent arrested by vibration.

In a railway siding, where the rails are seldom used, the rails are invariably coated with rust, while on the main line they are generally entirely free from rust, even under very unfavourable circumstances. Plates are also more durable when united in large masses than when in an isolated form. A singular instance of this occurred during the construction of the Britannia Bridge. A heap of rejected plates was left two years on the platform, where they became so corroded that they could be literally swept away with a broom; while precisely similar plates, employed in the construction of the tubes alongside, suffered no deterioration.

It is evident, from the foregoing remarks, that the painting of wrought-iron girders and roofs, more especially in the neighbourhood of smoky towns, is a precaution of the utmost importance. Every care should be taken to expose the iron as freely as possible to the air, to leave no hollow where water can collect, to avoid the contact of damp earth, and especially of vegetation, and to throw the material into the form of heavy bars rather than thin plates. Painting is more economically performed, and more effectual, when constantly attended to, than under the vicious practice of laying on three or four coats, and then leaving the work for years till it all peels off with a layer of rust attached to it. The Britannia Bridge furnishes a remarkable instance of the value of this system. On the completion of the work, the contract painting was carefully scraped, and the tubes thoroughly repainted, inside and out, in the year 1851. The maintenance has been effected by two or three men, constantly on the work, who attend to the slightest symptoms of local discolouration. It was repainted in 1866. The painting consisted of two coats of red lead, and two coats of stone colour; the last coat being thoroughly sanded, with dry silicious sand. The cells and the bottom are painted with tar paint; the plates being first painted with two coats of red lead. The interior of the cells has never been repainted. The Author does not hesitate to express his firm belief, that the total loss from rust, of the whole 10,540 tons, of which the tubes consist, has not in twenty years amounted to a single pound weight. A careful investigation, in conjunction with Mr. Hedworth Lee, the Engineer

of the line, shows no appreciable variation in the deflection of the tubes, so that it is impossible to conceive, under similar treatment, how any practical deterioration can take place in such a structure, even in several centuries. It may be remarked that the tubes are protected externally by a light framed boarded roof, covered with canvas and coated with tar paint. This useful paint is made as follows: coal tar, 9 gallons, slacked lime, 13 lbs., and turpentine or naphtha, 2 or 3 quarts; the whole being dredged over with sand. The addition of the quick lime is indispensable, to neutralize the free acid that exists in tar.

Cast iron, when exposed to the action of sea water, slowly decomposes; the iron being dissolved, leaving a graphite or plumbago. The action, however, is superficial and very slow. The cast-iron columns of the pier at Gravesend have suffered no appreciable deterioration, in thirty-four years. The action depends considerably on the quality of the iron; and although it is advisable to give a slight increase of thickness to plates used under water, the action is too slow to interfere with the use of this valuable material for submarine works of a massive character, the loss of material being insignificant in a long period of years. It is also preserved by painting, where it is accessible for that purpose, and by any protection which prevents continual renewal of the surrounding medium, as when surrounded by brickwork or masonry. In fresh water it suffers no such deterioration, and under ordinary circumstances its durability in a pure atmosphere appears unlimited.

In the case of zinc, although the bright metal oxidizes even more rapidly than iron, yet the oxide adheres with such tenacity to the metal, that it affords an efficient protection against the continuation of the process. To this property the metal owes its great durability, more especially as its oxide is insoluble in water. In the presence of any solvent of the oxide, this metal is so speedily destroyed as to be practically useless, unless protected by paint. In pure water its durability is, however, very great; and the conversion of a flat roof of zinc, into a tank always kept full of water, has been found extremely effective as a preservative; while it also moderates the effect of the sun's heat, which is peculiarly destructive to zinc, on account of the large amount of its expansion and contraction from changes of temperature. The most important cause of the destruction of zinc in smoky districts is due to galvanic action. In such situations the particles of soot, or carbon, deposited on the zinc, form one element, and the zinc itself another, of a powerful galvanic couple; while the sulphurous acid, and moisture of the atmosphere, complete the battery, or rather the myriads of batteries which cover the surface of the plate. A similar action produces the remarkable rusting away at the base of iron railings when fixed in stone work, as is usually the case by being run in with lead. The contact of

copper with the iron plates of a vessel is thus also a source of the greatest danger, and there are numberless other instances, in which the contact of metals of different conducting powers is equally destructive. In all such cases the use of paint furnishes at any rate a temporary remedy.

The difficulty of dealing with the great dilatation, which increase of temperature produces in the case of zinc, has led to the coating of iron plates with zinc, by simply cleaning and immersing them in the molten metal. As zinc, like other metals, may be thus deposited, through the medium of galvanic action, the name of galvanized iron has been given to iron so protected. It is difficult to over-estimate the value of the introduction of this process for the purpose of the Engineer. No material is more generally employed, though none requires more consideration, as to the circumstances where its use is advantageous. All that has been said on the subject of zinc applies equally to galvanized iron. In a clear atmosphere its great durability, its stiffness, its freedom from expansion, and its economy, are all qualities of the highest value; while on the other hand, without constant painting, it is wholly unfitted for the atmosphere of smoky towns, or manufactories, or even of railway stations where it is exposed to the fumes from locomotives. Both the corrosive and the galvanic actions, which in such cases are so destructive, do not cease with the destruction of the zinc, which is soon effected, but continue also to act, with fatal effect upon the iron itself, as may be seen in many railway stations and sheds near manufacturing towns. The corrosive tendency in zinc and iron obliges the use of the less oxidizable metals, copper and lead. Lead slowly absorbs oxygen and carbonic acid in moist air. It is acted upon by certain waters, and is occasionally riddled with holes by the larva of an insect, and its expansion and contraction require to be carefully allowed for in its use. Its ductility renders it a valuable material. Copper might, however, in many instances be used with great advantage in its stead, and the cost of a superficial foot of 16 oz. copper is no greater than that of a foot of lead; while its lightness and greater durability often render it a valuable substitute; and from its greater resistance to oxidization, paint adheres more permanently to copper than to either lead or zinc. The lead pipes and brass taps used at Pompeii for the fountains and baths have not suffered any deterioration, by being buried eighteen centuries beneath the dry volcanic ashes which cover the city. Nevertheless copper in a moist atmosphere slowly oxidizes, and a green carbonate forms on its surface.

The action of sea-water on copper is so important, that it deserves notice in connection with its use for covering ships, especially as some erroneous popular notions exist on this subject. The object in covering a vessel with copper is solely to prevent the adhesion of

barnacles and other molluscs, which in some seas increase so rapidly as to form a living envelope of solid incrustation, several inches in thickness. This property is not due to the poisonous quality of its salts, as is sometimes asserted, nor is it used as a covering for ships on account of any durable properties it possesses. On the contrary, its value depends on its slow destruction. The barnacles adhere as freely, and with as much impunity, to a copper plate as to a zinc or iron one; but the chloride of copper which forms beneath the attachment being a soluble salt, the creature no sooner effects a lodgement than it is at once set free by its solution; while the salts which form on zinc or iron being insoluble, the plate is rather protected than otherwise by the tenacious parasite. The same effect takes place with any metal totally unoxidizable, as gold or platinum, which would be quite useless for ships' sheathing. Hence the difficulty of devising an efficient paint for iron ships; for while, on the one hand, it must be slowly soluble in water to prevent this adhesion, it must, on the other hand, be sufficiently insoluble to be durable. It is remarkable that a most efficient covering for vessels is obtained by simply coating them with tallow, and doubtless for the reasons above assigned. Ordinary oil paint forms the most efficient material for protecting either metals or wood from the effects of moisture and air, which are in almost every case constant agents of destruction. The material, however, is only protected at the expense of its covering, as all oils, resins, and gums, exposed to air, and especially to the light of the sun, oxidize and burn away with more or less rapidity, leaving a powdery residue behind. Whatever the solid ingredient in paint may be, either lead or zinc, its adhesion depends on the oil or varnish with which it is mixed, and their preservation should, therefore, be a primary object of consideration. Now, the gums and oils differ from other materials in this respect, that they are but little affected by moisture, and they perish most rapidly in light and air, where most other materials undergo no change. Gutta percha and some others seem, indeed, to be indefinitely preserved by water. The gutta percha now used for telegraph purposes, when laid under ground, is found to be far more durable in a wet pipe than in a dry one; and it was found to be so rapidly decomposed when exposed to light and air, that the Author introduced the practice, which has since become universal, of covering it with tarred or painted tape, to preserve it both from the loss of the water, with which it is always combined, as well as from oxidization. But, though the oils and varnishes used in painting are but slightly affected by water, they are singularly soluble in damp places; and paint, as before observed, in such situations rapidly assumes the liquid form, however thoroughly it may have been first dried and hardened.

As a preservation of paint against the heat of the sun and light,

the Author would direct attention to the virtue of a coating of silicious sand, dredged on the paint while wet. He has, in a damp situation, a larch pilaster, supporting a sun-dial, which was painted and sanded thirty-five years ago; and, though the wood is cracked, and partially decayed at the base, the sand is still perfect, and the surface bears even now a resemblance to stone. This is due to the particles of sand becoming so closely imbedded as to exclude air and light. In situations where repainting is a difficult operation, as in the case of a building, or verandah, overgrown with creepers, the most durable paint the Author can suggest is, first, two coats of good oil and white lead; secondly, a coat of good copal varnish; and, thirdly, two additional coats of white-lead paint, the last being thoroughly sanded. The varnish adds great tenacity, and is thoroughly preserved by the overlying paint and sand.

The limits of this Paper prevent numerous other practical deductions being pointed out that the subject must suggest. It has, indeed, been thought desirable, that no undue prominence should be given to mere technical deductions, however valuable.

The durability of matter is a subject of the highest philosophical interest. The universal law on this planet appears to be, that no form shall be permanent. Never-ceasing destruction and reconstruction are characteristic, within the range of the atmosphere, of everything that exists, whether as regards organic life or inorganic matter; and it is probable that even the atmosphere itself is subject to the same decree. In such a changing scene the works of man are but as scratches on a shifting beach.

It is a curious subject for speculation to compare such a transient habitation with the apparently unchangeable aspect of the attendant planet, the moon. In the absence of any atmosphere, at any rate as regards moisture, the great element of all the instability of this world appears to be wanting; without moisture no vegetation can decompose, or fertilize, no frost can disintegrate its arid barren rocks; without organic changes even chemical action must be equally powerless; and the dull, cold, monotonous appearance presented by its surface, is perfectly consistent with the barren eternity to which it seems condemned. Though sometimes, in ignorance, the perishable character of all surrounding things may be lamented, yet on the other hand it must not be forgotten that perpetual destruction and perpetual renewal are in reality the essential causes of all life, beauty, and harmony.

[Mr. Clark

Mr. Clark said he had not ventured to broach any theory, or to advance ideas which required defending, or which could be attacked; indeed the Paper was more tentative than anything else. He had been struck with the extraordinary difference in the durability of materials under varying circumstances, and he had alluded to the iron roofs in Geneva and St. Petersburg, the temples in Italy, and other instances, which clearly illustrated the fact, that the durability of materials depended much more upon the circumstances in which they were placed than on any other cause. Many other interesting examples of these apparent paradoxes might be mentioned.

Mr. S. B. Boulton wished to direct attention to a curious fact connected with the durability of timber, a material to which he had devoted a good deal of attention during the last eighteen years. In the course of a previous discussion at the Institution, a piece of creosoted timber was exhibited,[1] which had been attacked by the teredo, and it was said that the timber had been creosoted at Amsterdam. By a singular accident, he happened to be in Amsterdam two or three months after, and while visiting the Royal Museum was shown a piece of the same pile. This had been attacked by teredines, which had penetrated through the uncreosoted part of the wood, and had worked their way into the interior. It was his opinion, however, that if the wood had been creosoted under better conditions, the same circumstances would not have occurred. A few months afterwards, twelve pieces of fir, twelve of beech, and six of poplar, being the kinds of wood used by the engineers in the construction of the dykes, were sent to this country, and were thoroughly creosoted. They were then returned, and were placed in the same position as the piles which had failed, that was to say some at Nieuwe Diep and the rest at Stavoren. About a year afterwards, he received one of the printed reports of the Commission appointed by the Government to report upon the ravages of the teredo, from which it appeared that the specimens were then perfectly sound. The first year a piece had been cut off the timber, to see that no cells of the teredo had been formed in it, and it was then replaced in the water. In the subsequent year another slice was removed, and the wood was still found untouched, and had remained uninjured. Another series of experiments was made by the Ingénieurs des Ponts et Chaussées in Belgium, who had also turned their attention to the subject of preparing timber against the attacks of the teredo. These experiments extended over a period of ten years, when it was found that creosoting was a preservative against the attacks of marine insects. The Belgian Government had adopted creosoting not only for wood

[1] *Vide* Minutes of Proceedings Inst. C.E., Vol. xix., p. 665.

placed in sea water, but also for sleepers for the State railways. Another series of similar experiments had been conducted for the French Government, for a number of years, by M. Forestier, Ingénieur en Chef des Ponts et Chaussées du département de la Vendée. A creosoting establishment had been placed at his disposal at the Port of Sables d'Olonne, and he had found the same results follow. M. Forestier had published a pamphlet, which was almost an exhaustive treatise, on the subject of this destructive worm, in which he laid great stress on the fact that, hitherto, the wood had not generally been impregnated with a sufficient quantity of creosote. The French Companies and the Belgian Government paid particular attention to the wood being well dried before it was creosoted. It was stacked in yards for from four to six months before the preparation took place; and in order to insure this being done, as dry sleepers or dry timber of any kind could not be procured, unless those who provided the wood were interested in getting it stacked for the proper length of time, the system was adapted of examining the wood as it arrived from foreign ports, and, upon approval, of paying over at once to the contractors from four to five-sixths of the total price of the sleepers. These were then stamped with the Company's mark, whose agent saw that they were properly stacked; and after some months, when thoroughly dry, the sleepers were creosoted, and the balance of the price was paid.[1]

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[1] In connection with this subject, Mr. Boulton presented to the Institution the following official pamphlets, together with English translations of portions of them:

1. "Préservation des Bois contre les attaques du Taret (Teredo Navalis)." Notices par M. Forestier, Ingénieur en Chef des Ponts et Chaussées du département de la Vendée."

In this pamphlet the Author narrated his own experiments with wood prepared at the Creosoting Works of the French Government at Sables d'Olonne, and which he had found to resist the attacks of the teredo when exposed to its action in the waters of that port. He related the results of similar experiments at a number of other seaports in different countries of Europe, including (at pages 27, 28) an account of the fact mentioned by Mr. Boulton as to the successful results obtained with creosoted wood in Holland. The pamphlet was dated April 10, 1867, and the following was a translation of its concluding remarks. "The efficacy of creosote consequently appears to us to be an established and incontestable fact, with the sole condition that it be of good quality, and that it be injected into the wood in sufficient quantity." M Forestier (at page 32) estimated this sufficient quantity for timber in sea-water to be at least 300 kilogrammes per cubic mètre of wood, which was equivalent to about 19 lbs. per cubic foot English measure. By a subsequent letter M. Forestier stated that he had, on March 6, 1868, re-examined all the specimens of creosoted wood at Sables d'Olonne, and that this inspection confirmed his previous convictions on the subject.

2. "Verslag over den Paalworm." Three pamphlets, dated 1863, 1864, 1865, being the fourth, fifth, and sixth reports (the latter being the last as yet published) of a Commission of Engineers and other members of the Royal Academy of Sciences of Amsterdam. They were appointed, under the authority of the Dutch Government, to investigate into and report upon the dangerous and destructive ravages of the teredo navalis upon the timber used in the construction of the dykes

Mr. H. Conybeare agreed as to the necessity of thoroughly drying timber before creosoting it. At present the creosote generally penetrated but little more than skin deep, for when damp timber was operated on, it was obviously impossible under any

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or embankments round the coast of Holland. The Commissioners report as to the results of their experiments during six consecutive years with greenheart and a great variety of other hard woods, procured from different tropical countries, also with wood impregnated with a number of different substances. In their several Reports, No. 4, page 3; No. 5, page 15; and No. 6, pages 5 and 19, they allude to the success of the creosoted timber sent to them by Mr. Boulton. They arrived at the conclusion that the hardest and best tropical woods which they had been able to procure, including greenheart, American oak, &c., were not exempt from the action of the teredo. They related several instances of creosoted wood having failed, in each case establishing the cause of failure as arising from imperfect preparation. They recorded also the success in every case of wood properly injected with creosote. They reported the failure of a variety of other substances with which they had either impregnated or coated over the timber. And in the last Report, pages 5, 6, and 19, they confirm their previous conclusions and resume in these words :—"That a good preparation by means of creosote preserves wood from the attacks of the teredo."

3. "Sur le Taret et les Moyens de préserver le bois de ses dégâts." By E. H. Von Baumhauer, of Harlem, one of the Members of the Commission above mentioned.

This pamphlet gives a résumé of the foregoing reports, and adopts the conclusions of the Royal Commission; it contains also a detailed description of the natural history of the teredo, and its manner of working, accompanied by engravings. By a letter dated the 2nd of June, 1868, M. Baumhauer states that the creosoted wood in the port of Nieuwe Diep was inspected in March, 1867, by the Engineer-in-Chief of the province of North Holland, and was found exempt from the ravages of the teredo, after exposure to its attacks for more than seven years.

4. "Notes sur la Préparation des Bois," by M. Charles Coisne, Chef de Section à l'Administration des Chemins de Fer de l'Etat Belge. This Report gives a description of the mode of creosoting wood, for the use of the Belgian Government, from 1858 to 1867, at the establishments of Messrs. Burt, Boulton, and Haywood, at Ghent and Ostend, and at that of Mr. Bethell at Antwerp. M. Coisne (page 22) recommends the adoption of creosoting for all railway sleepers, and advises an injection of 250 litres per cubic mètre.

5. The Report of M. Crépin, Engineer of the Belgian Ponts et Chaussées at Ostend, was contained in the pamphlet of M. Forestier, commencing at page 9. M. Crépin gave the result of a series of experiments extending over ten years, from 1857 to 1867. He found that unprepared woods, and wood prepared by sulphate of copper, were rapidly attacked by the teredo. His first experiments being made with wood insufficiently prepared, he found the teredo penetrated the uncreosoted part, but left untouched the part creosoted. By order of the Belgian Government, a number of pieces of wood were then creosoted at the Ostend Yard, by Messrs. Burt, Boulton, and Haywood, with a very complete injection of creosote. These timbers had been entirely successful. M. Crépin concluded (page 18), "you can affirm, that as far as concerns the experiments made at Ostend, the creosoted timbers there are completely preserved from the action of the teredo."

The same conclusion might be arrived at from all these experiments.

1. That timber should in all cases be thoroughly dry before creosoting.

2. That for timber exposed to the action of marine insects, a much larger quantity of creosote was required than had usually been adopted in England.

The limnoria terebrans did not appear to infest the Dutch, Belgian, and French ports referred to in these Reports; though it was probable that the increased quantity of creosote, which had proved so effectual against the teredo, might also succeed if tried against the limnoria.

pressure to force the solution into the pores, which were already pre-occupied by an incompressible fluid. To prepare sleepers, they should be stacked and dried beforehand in a heated shed or hot chamber, as the rifle-stocks were dried at Enfield, till every particle of moisture was thoroughly evaporated. They should then pass directly from this hot chamber into the creosoting tank, which should not at first be quite filled with the solution, in order that a vacuum might be established by an air-pump, until bubbles had ceased to rise from the sleepers, and the tank should then be filled and hydraulic pressure applied. This would insure the thorough permeation of every pore with the solution. Mr. Brunel's opinion was on record that timber, thoroughly creosoted, would last forty years; and no engineer ever gave more attention than he did to the processes for preserving timber, or applied them more successfully, as the long duration of his timber viaducts proved.

Mr. George Farren considered that an accomplished engineer should be not only a good mathematician and physicist, but a good mineralogist, chemist, and geologist as well. He thought, however, that chemistry had not hitherto occupied its proper position in the education of the Civil Engineer, and it appeared to him that it was to this that the Paper seemed directly to point. The Author had drawn together a number of interesting facts, some of them most contradictory at first sight, showing the different and occasionally unaccountable behaviour of the same materials when placed under somewhat different circumstances: but all these differences could be undoubtedly traced directly to chemical action. To the slender and simple list of materials enumerated in the Paper, which the engineer was to use, and therefore to study, the element oxygen should be added, for among the elements it was the most abundant, forming no less than one-third by weight of the world, and it was by far the most active of all. In his opinion it was one, the action of which should occupy an important place in the consideration of the Civil Engineer, as to its incessant action might be more or less directly traced many of those influences upon which the consolidation or perfection of work depended; but which influences, unless properly guarded against or intelligently controlled, no less assuredly were also the most powerful agents in the destruction of it.

He would take this opportunity of mentioning an interesting and curious fact, relating to the behaviour of iron, which had been pointed out to him by Professor Bloxam, of King's College and Woolwich Arsenal. It was well known that dilute nitric acid had a strong action on all but two of the metals, and on iron amongst the number, but if a piece of bar iron was first immersed in pure nitric acid for a length of time, and was then immersed in dilute nitric acid, the latter would be found to have no effect on the iron.

It seemed to be altogether protected by having been first immersed in the strongest nitric acid. Many purely chemical applications had been devised for the purpose of protecting iron from oxidation without attaining perfect success, and whether this curious action of nitric acid on iron might some day furnish the clue to the discovery of a preservative of iron was more than he could say.

Mr. Shoolbred observed with regard to the durability of zinc in this country, that it was principally used in sheets as a roofing material, and also as sheathing for vessels. British zinc was mainly derived from spelter, which was found in Cornwall; and zinc was also extracted from the mines of the Vieille Montagne Company in Belgium, Germany, and elsewhere. Generally speaking, from what had come under his observation in this country, it was acknowledged that the Belgian zinc was superior to the British in its wearing power and durability, and this was shown by the former costing about £1 per ton more than the latter.

He had been furnished with a list of the roofs of buildings put up in this country by the Vieille Montagne Company,[1] and he would mention three examples to show the durability of the zinc.

In the case of the cloisters of Canterbury Cathedral, the ecclesiastical architect stated that he had inspected them, and found they were in a perfect state of preservation, after having been up more than thirty years. Another instance was the dockyard sheds at Portsmouth, where, after a period of over seventeen years, three specimens taken from the roof, were found to have lost, on an average, only $\frac{1}{2}$ oz. per square foot by oxidation, the original weight having been 16 oz. The third example was at Swansea, in an atmosphere which, it was feared, would do much harm to the zinc, in consequence of the chemical properties of the gases from the copper works with which it was polluted. In this case a roof, which had been up more than ten years, had been lately examined, and found in a state of perfect preservation.

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[1] Vieille Montagne Zinc Mining Company.

List of Buildings covered for some years with Zinc.

The Cloisters, Canterbury	33 years.
Portsmouth and Devonport Dockyards (Slip Shed)	24 „
Great Western Railway, Reading Station	20 „
Blackwall Railway, London Terminus	20 „
South Eastern Railway Stations	20 „
Tunbridge Station	15 „
South Wales Railway Stations	15 „
Greenwich Royal Hospital	15 „
Abingdon Railway Station	14 „
Oxford and Rugby Railway (Banbury Station)	12 „
Wilts and Dorset Railway (Frome Station)	10 „
Oxford, Worcester, and Wolverhampton Railway	10 „
Works at Swansea	10 „
Woolwich Arsenal	5 „

For sheathing vessels, the Belgian zinc likewise presented a superiority over the British spelter, as he was given to understand that the ordinary British zinc required to be removed after each voyage, averaging about twelve months, whereas the Belgian zinc lasted, on the average, three years, and sometimes six years or seven years. He had never heard of paint being used as an antidote against oxidation; and he believed the Vieille Montagne Company never, under any circumstances, used it, nor had they found any necessity for so doing.

The injury sustained by galvanised iron had been attributed to the destruction of the zinc; but in the cases which had come under his notice, it seemed rather to arise from the detachment of the coating of galvanised metal from the rest, by the corrosion of the layer of iron immediately beneath it, which therefore allowed the galvanised one to peel off.

Mr. J. M. Heppel said, when in charge of the Madras Railway, he observed that rails which were stacked in the neighbourhood of the sea decayed rapidly, whilst rails laid down in the immediate vicinity of the station in Madras, and exposed to the traffic of frequent trains, did not perceptibly suffer deterioration. This attracted his attention so much, that he had caused some rails which had been stacked for several years to be carefully cleared of all the product of corrosion and weighed, when he found that they had lost nearly 3 lb. to the yard, whilst others close by, exposed to the same atmospheric influences, but subject to the passage of trains over them, had suffered no apparent diminution of weight. Many other engineers had observed the same fact; but he had never heard any one able to account for it.

Mr. Beardmore believed that rottenness depended on damp, or, in other words, absence of evaporation, as when the temperature of the dew-point was equal to that of the air. The dampness of a cellar was proverbial; but in many cases the cellar was no more damp than any other place. The temperature of a deep cellar would be about 50° Fahrenheit in England; and if it were exposed to the free access of a saturated current of air above this temperature, the result would be a deposition of moisture. So, if rails or timber were stacked in such a position as to be shaded, the interior parts were frequently cooler than the atmosphere around; when under such conditions, the air being nearly saturated with vapour, there would be a deposition of moisture, and the iron or wood would become damp, and decay. Both iron and wood, when well exposed, proved durable, but either of them, if screened from the sun, and from proper circulation of the air, were liable to destructive action.

In places far removed from the sea, where the rainfall was small, as on the broad plains of Western America, or of Eastern Europe, or

Siberia, the decay of iron and wood was very slow. It was marvellous how hammered thin iron plate, unprotected by a coating of tin, or even fir-timber, in favourable situations, lasted in Russia, although greatly exposed to the elements. This was owing to the excessive dryness of the climate, and the consequent absence of deposition of moisture.

Mr. W. H. Barlow did not think the presence of damp quite sufficient to explain the decay of iron rails. It was not only in rails that were stacked, but in rails laid in a siding not much used, that this was observed. The great difference between the effects shown upon rails laid in a siding and rails laid in the main line was, that the one by the wear of the traffic had a polished surface, and the other had not; and he thought it was quite possible that a galvanic action arose between the polished and the unpolished surfaces, which tended to preserve the general body of the rail. In no other way could he account for the preservation of the rail; but it was an undisputed fact, that rails in sidings decayed by rust much sooner than in the main line.

Mr. Beardmore attributed the fact of the plates used for roofing throughout Russia resisting the damp so well, to the extraordinary amount of hammering given during their manufacture.

Mr. G. J. Symons remarked that a series of experiments had been conducted at the cost of the British Association,[1] with the view of testing, not only the relative wear of rails in use and out of use, but also of rails in and out of the magnetic meridian. No doubt damp had a great effect on the durability of zinc and other metals; but, inasmuch as rain and dew were not pure water, for they contained various acids and salts in solution, he imagined that it was not water alone, but water with the addition of the salts which produced the effect. The Author had referred to the destructive agency of damp, as distinguished from moisture, and had half hinted at the possibility of there being some kind of minute sporules, which ultimately developed into fungi; he could corroborate this opinion, as he knew of instances in which such sporules were excessively numerous, and were readily detected by passing a large quantity of air through water. Within the last few days it had been suggested to him as not at all improbable, that the slow oxidation of metals exposed to the atmosphere might be advantageously applied to obtaining some of the softer tints in engraving, which it was almost impossible to obtain by the ordinary process of passing a layer of acid over the plates.

Mr. H. S. Bethell observed, that Papers had recently been read before the Manchester Philosophical Society, in which it was stated that, not only were insects found in the atmosphere in cases of disease, but that the fungi which occasioned mildew had also been

[1] "Report of the British Association for the year 1849," pp. 88—112.

found. Drawing a distinction between decay of ligneous fibre, and the dry-rot or putrefaction which originated in the sap, he thought that temperature had a great deal to do with the effect of damp in causing putrefaction of timber. Suppose a close room, where decay had already commenced; that was to say, where an oxidation of fibre, and an absorption of water had taken place. By such chemical and mechanical means considerable heat would have been generated, and the spores of the dry-rot fungi in the air would be found in a hot and damp atmosphere, like that in the time of the carboniferous period, when plants, which under ordinary circumstances would grow very slowly, were developed with surprising rapidity. In his opinion, putrefaction of timber only occurred in confined situations, where decay or oxidation had taken place, and in a soil suitable for the spores of dry-rot fungi to germinate, where heat favoured their rapid development. Few cases could be shown in which putrefaction in wood had taken place where there was a draft of air, though in such situations decay had often occurred.

It was necessary for the preservation of wood, that all water and air should be drawn out of the pores, and that the exterior fibres should be more or less coated with a waterproof material, to preserve them from oxidation, or decay. To prevent putrefaction it was also most important to remove all water and oxygen from the pores, because the water which got into the wood in those foreign countries whence most wood came contained decomposed and putrefactive matters; and the air in the holds of ships was of a damp tropical temperature, and so favoured the growth of dry-rot fungus. No doubt a great deal of the wood imported into England was not only decaying, but positively putrefying on its arrival.

Mr. Pole stated that he had considerable doubts as to the durability of wrought-iron bridges, owing to their liability to be damaged by rust. It was very much the practice in the present day to use wrought iron for bridges of all kinds, even in cases like arches, to which it was less favourably adapted than cast iron; indeed, the substantial class of iron-arch bridges, of which the Southwark was so fine an example, might be said to have become obsolete, a result, he thought, greatly to be regretted. It had also become the custom now, to form the bridges of bars and framing of light section, a plan, which, while he admitted it gave much scope for skill in design, and for economy in first cost, was the worst adapted for durability, inasmuch as the surfaces of these small bars offered increased opportunity for the oxydizing action. Moreover in the places where the bars or frames crossed, or were bolted or riveted together, the speedy destruction was rendered almost certain, as the water got into the interstices, and the motion of the parts, caused by the traffic, hastened the corroding action.

Painting was, no doubt, a great preservative, in the exposed parts, but in many cases (particularly on railways not prosperous in their finances) there was no security for its being properly carried out and renewed when necessary: and at the best it would not preserve the joints and surfaces of contact. He was glad to hear so good an account of the present state of the Britannia Bridge, but he feared that the more modern structures would be less fortunate, and that the lapse of a comparatively short period would find them in a condition to give cause for much disquietude. He thought it a grave question for the profession, whether the use of light wrought-iron structures was not being carried too far.

Mr. Pole would add his testimony to the value of this class of Paper, embodying the result of thought and reasoning. He would on no account disparage Papers of a descriptive character, which were of great practical utility; but he hoped the example set by the Author would be followed, and that Essays involving high attainments would be produced which would serve to elevate the scientific character of the Institution in the eyes of the world.

Mr. J. W. Bazalgette approved of the adoption of cast iron in preference to wrought iron in situations where structures were peculiarly subject to decay. He had lately built a wrought-iron aqueduct for conveying sewage. He had found, by the result, that it was not a wise selection, and he had since adopted cast iron for similar structures, because, at any rate, a thicker material was thus provided at a less cost.

Mr. Vignoles, Vice-President, remarked that formerly a great deal was written as to the benefits that might arise from the impregnation of timber by various compounds of metals, creosote, and so forth, though latterly the subject seemed to have been lost sight of. Long experience and reflection had left him in greater uncertainty than when he began, thirty years ago, to consider the subject; and he was doubtful whether any rule had been yet arrived at, by which it could be ascertained how far creosoting or the other impregnations of timber by metallic agents could be depended on. He could quote instances of uncreosoted timber that had lasted very many years, and of creosoted timber that had not lasted five years.

It had been insisted on latterly that iron sleepers were better than timber sleepers; but he did not agree with that opinion. No doubt many instances had been brought forward in which they had proved successful; and the general result appeared to be this, that where there was a sand or gravel embankment, and good dry ballast, the iron seemed to be superior to timber. If, however, iron sleepers were substituted for timber sleepers, there was a loss of elasticity, so that the gain in the one case was counterbalanced by an increase of expense resulting from the other. On the whole, he preferred timber sleepers.

As regarded the application of wrought iron and of cast iron, he fully agreed with Mr. Bazalgette, from experience acquired in a great number of instances, beginning with the iron bridge at Southwark. There was yet much to learn, and much to apply. The various positions in which the iron should be placed ought to be considered; and the strains and counter-strains to which it would be subject. Generally speaking, for moderate spans, cast iron would suffice; but when the span was large, wrought iron was preferable.

Mr. A. Giles said, his experience was precisely the reverse of what had been stated as the result of experiments at Amsterdam. He had creosoted piles so well that, by great pains being taken, 10 lbs. of creosote to the foot were absorbed by the timber. Those timbers had remained sound for the first four or five years; but after that time had yielded to the ravages of the limnoria terebrans, and, after having been only twelve years in the water, were now reduced to about one-quarter of their original bulk below low-water mark. He believed that when creosoting was not carried out to the extent of 10 lbs. of creosote to the foot, nothing like so good a result could be obtained. He had also tried Kyan's process of pickling timber; and, as some works under his charge were little better than fungus pits, he had taken the opportunity of placing the prepared timbers in them, and had found that the Kyanised timber decayed as fast as any other. His experience in that work was that the duration of timber was from twelve to fourteen years.

It was a matter of general observation, that where rails were in constant use, from trains passing over them, the loss from rust was very small; the waste was simply due to the abrasion of the wheel. At the same time, in iron steam vessels, where there was constant vibration from the engines, corrosion took place to a serious extent. That could only be remedied by frequent painting, or by covering the inside of the vessels, as was now commonly done, with cement.

Some remarks had been made on the durability of timber on the Continent of America; but it was notorious that American sleepers generally lasted only about six years. The timbers of the roof of Westminster Hall were quite sound, and they had been there hundreds of years; and in Germany, he himself had seen in Brunswick several houses with the date of about 1400 cut on the timbers, and those timbers were unimpaired.

Mr. T. Marr Johnson believed that the duration of wrought-iron plate bridges was a mere question of care: if kept clean, well painted, and otherwise properly tended, they were practically imperishable; if neglected, they were proportionately short-lived.

He could bear testimony to the extreme care which the Americans and Canadians take of their wrought-iron structures. The Niagara and Cincinnati wire bridges, for example, were constantly cleaned, repaired, and painted. He had recently passed through

the Victoria Bridge, at Montreal, and found it in first-rate order; it was roofed over with tin, and appeared to be well maintained; as far as he could judge, it had lost nothing by oxidation, except perhaps in the bottom plates, resulting from the drip of the locomotives. He thought, however, that lattice or other open work would be more durable in the climate of Canada than plate sides, as it would permit the sun's rays to act more equally upon the two sides of the bridge, which the plates would not, one being in the shade of the other, resulting in unequal expansion, and causing somewhat injurious strains upon the parts of the tubes.

He was surprised at the great difference in duration of the timber bridges, so extensively adopted in the United States, when roofed in, and when exposed to the weather; in the latter case he was credibly informed that their life was but seven or eight years, but when covered in, the same bridge would last thirty years or more; the reason they were not more generally covered in was because the money could be more profitably expended in extending the railway into new country than in protecting the existing works. These bridges were excellent examples of carpentry; were frequently made of pitch pine, not painted or tarred, and were most commonly on the Howe truss principle, the compression members of which were proportioned to bear maximum strains of 700 lbs. to 1,000 lbs. per square inch.

It was true, as had been stated, that sleepers in the Western States lasted but six or eight years; they were of oak or black walnut, round timber, a large proportion of which was sap; they were frequently used very green, and were exposed to a good deal of hard usage, the rails being generally attached to them with dog-spikes, and not being very accurately bedded. The ballast was often very scant, and of inferior quality, which facts might account for their short duration.

Mr. E. B. Webb knew of timber which endured even better below than above ground in damp situations. He had seen timber-posts which had stood in damp ground for upwards of one hundred years, the part above ground having received injury from the weather, whilst that below was perfectly sound, and retained the marks of the axe as well defined as when first made. The statement, therefore, that dampness was destructive of timber required qualification. The timber to which he had alluded grew in Brazil, and it could be obtained in considerable quantities in the interior of that empire. The best kind was called Grauna, but there were several descriptions of similarly durable wood. Although he had referred to wet ground, yet the same timber appeared indestructible in any kind of ground or position, except when placed in the sea. He would add that the sleepers on the Panama Railway were of timber apparently indestructible, called

Guayacon, and were, for the most part, taken from the forests on the banks of the Magdalena River: and large numbers of the sleepers on the Cuban railways were obtained from the same source, and were looked upon as indestructible.

Mr. J. Brunlees had often heard that the Britannia Bridge was suffering much every year from rust; and he hailed with satisfaction the assurance which had been given that such was not the case. The test that had been applied was the surest proof that the iron in the bridge was not suffering from decay.

To preserve cast iron, he had been accustomed for the last fifteen years to boil it in a preparation of tar and asphalte. He believed Dr. Angus Smith had recommended this process to Mr. Bateman for coating the pipes used in the Manchester waterworks; but while Mr. Bateman used a spirit in connection with the tar and asphalte, he used those ingredients alone, as he found that the spirit made them too hard, and the surface produced was likely to be broken from chipping and other accidental causes. The iron was dipped when warm in the preparation, which was heated to near the boiling point. He had also used the same preparation for wrought iron, but the work had been principally sent to foreign countries, and he could not yet speak as to the result. He had specified that the rails for the San Paulo Railway should be coated with the same mixture, and when he was in Brazil he had found them as fresh as the day on which they were sent from the works. Although many of the rails were alongside of and some in the water, yet both on the quays and on the works he found them in perfect preservation, and he would therefore recommend the use of a similar coating before rails were sent to foreign countries.

Mr. E. W. De Rusett observed, that the use of distilled water was the first cause of the destruction of marine boilers, as no scale could form on the plates, from the want of lime or other earthy matter to be deposited; consequently the plates were subjected to the action of the fatty acids, and copper, &c. collected by them when passing through the tubes of the surface condenser, as well as to the constant friction of any insoluble matter in the boiler. This was remedied by introducing a sufficient quantity of sea-water to produce scale, either above or below the tubes, in the surface condenser, so that it was pumped into the boiler with the feed-water. The surplus was blown off as in ordinary practice.

The theory that the vibration of passing trains preserved the rails from rust did not apply to steamvessels as some persons seemed to think. Steamvessels were certainly subject to vibration, but it was not produced by concussion as with the rails; and besides, rails were exposed to the drying action of currents of air, not so the holds of vessels; consequently any saline particles which found their way into the vessel were not evaporated, hence the

rusting. This was obviated to a considerable extent by the use of red lead or asphalte, care being taken to scrape the plates thoroughly, so that the paint should be in close contact with the metal.

Another source of destruction, if the plates were not sufficiently protected, was the constant wash of the bilgewater, which soon eat off the heads of the rivets, when they too were washed with the water, and grooved out the exposed plates evenly between the frames, as though a cold chisel had been dexterously used. In the P. and O. S. S. "Ripon," after fourteen years' service, the exposed plates, originally $\frac{11}{16}$-inch thick, were worn to $\frac{3}{16}$-inch, and the landing edge of the inside strake was worn to a knife-edge. As a preventive, Portland cement was laid in the bottom between the floors, as high as the limber holes, so that the water might not stagnate, but flow to the pump strum and be pumped out. This system likewise prevented leakage, as the cement, if properly applied, adhered firmly to the iron.

Another cause of decay was external friction combined with rust, of which a remarkable example was afforded by the P. and O. S. S. "Bengal." After fourteen years' service, the strakes were examined by drilling small holes in various places, and gauging them. The loss of thickness in the plates was as follows:—

	As Built, 1853.	After 14 years' service.	Loss.
	inch.	inch.	inch.
Garboard Strake	$\frac{14}{16}$	$\frac{14}{16}$	0
Garboard to 4 feet water-line	$\frac{12}{16}$	$\frac{12}{16}$	0
4 feet water-line to 6 feet water-line .	$\frac{12}{16}$	$\frac{10}{16}$	$\frac{2}{16}$
6 „ „ 12 „ „ .	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{1}{16}$
12 „ „ 16 „ „ .	$\frac{10}{16}$	$\frac{7}{16}$	$\frac{3}{16}$
16 „ „ 18 „ load water-line	$\frac{10}{16}$	$\frac{6}{16}$	$\frac{4}{16}$

It would be seen that internal rust could have had but little to do with such results, as the loss varied so greatly. In the flat of floor there was no diminution of thickness; but it was above the turn of the bilge, or from the 12-feet water-line, that the greatest amount of loss occurred, and particularly at the 18-feet line, where it was $\frac{4}{16}$ inch.

Mr. E. A. Cowper remarked that the grease in boilers in which distilled water was used became so acid by continual boiling as to be nearly as destructive as sulphuric acid, and the holes corroded were sometimes as large as split peas or beans. The neutral base

or glycerine was taken out of it by the water. A little chalk lime or magnesia put into the water, prevented that, as the lime combined with the acid, and thus formed an insoluble soap of lime. The lime, or magnesia, might come from the sea water if the boilers were worked with salt water. He added that a timber pile in good sound clay would in his opinion last one hundred years.

Mr. Clark said, in replying upon the discussion, that he had purposely made no allusion in the Paper to the various methods of preserving timber or stone, because he wished to keep it as theoretical as possible. He would endeavour to give some explanation of the cause of rust in rails lying alongside a line and not in use, while those in use and subject to vibration were free from it. In the course of the construction of the Britannia Bridge about one hundred thin plates were delivered, which were not used on account of some error in their dimensions. They were left on the platform alongside the Straits, exposed to the wash and spray of the sea; and, after about two years were literally so completely decomposed as to be swept away with a broom into the water, not a particle of iron remaining. As plates in every respect precisely similar suffered no corrosion when put into the tubes, it was natural to inquire into the cause of this great difference. The circumstances were identical, except that, in the one case, the plates were united into a solid mass, and in the other the plates were unattached and were separated from each other by flakes of rust, and so were more or less insulated. Chemical action was invariably accompanied by electric action. It was, therefore, probable that the difference in the electrical conditions, or rather the different electrical capacities of the large and small masses, might explain this great difference in their durability. To test this, he cut two pieces of plate 4 inches square and $\frac{1}{4}$ inch thick, and after cleansing them carefully, attached them to the outside of the western tube, but with this difference;—one of them was riveted to the tube, so that it was in direct metallic communication, and formed part and parcel of the tube; but the other plate was separated from the tube by a thick glass insulating rod. The difference in the oxidation of the two plates was evident, as in the course of eighteen months, the plate in communication with the tube was scarcely affected by rust, whereas the plate insulated by the glass arm was decaying rapidly. Unfortunately in painting the tubes, a platform was put up which destroyed the two plates, and so the experiment ended. It was, however, evident that the more rapid decay of the small insulated plate was due to its insulation. It might be said that, in a railway-siding, the rails were in the same position as in the main line: but in the main line, from the continual passing of the trains, the rails were brought into electrical contact with the chairs and each other, and they formed part of a

mass; while in the siding, rust, which was a good non-conductor, accumulated sufficiently to separate the rails from the chairs and each other.

It had been very properly remarked that wrought iron was not necessarily a durable material. The durability of the Britannia Bridge was entirely due to the great care taken for its preservation. The ridge was not painted now and then, but it was continually being painted. There was a man there to watch, and as soon as there was the slightest discoloration, before any spot could turn yellow, it was at once scraped and painted, though no doubt if this were neglected, the damage would soon become but too evident. He was sorry to say the rule appeared to be not to preserve iron structures at all. It was painful to see the large number of magnificent roofs and bridges rapidly going to decay for the want of care and a constant small outlay in paint. Many iron girders, built within his time, had been renewed, and there was great danger of serious accidents some day occurring from the neglect of these wrought-iron structures. The lower flanges of bridge girders were frequently covered with ballast and vegetation, and the mischief was not visible; but, if the rust and mould were scraped off, the extent to which the plates were corroded and damaged would be found to be much greater than was imagined. Similarly, iron roofs were generally carelessly painted in the first instance, and then totally neglected; the rods were covered with large flakes of rust, which fell away, while the corrosive atmosphere in the station found always a new surface to act upon, and produced a rapid decay; and many stations were suffering severely from that cause. He regretted that so little care was taken with wrought-iron structures; wrought iron, although an excellent material when properly attended to, was not only a bad, but a dangerous material when neglected; and it was inexcusable not to protect that which was so easily protected.

Galvanised iron was not suitable for the corrosive atmosphere of many of the manufacturing districts; but in the country, and in a purer atmosphere, there was no material more valuable or useful. A wrong estimate of its value had been formed from the fact of its being used for roofs in places where it ought not to have been used. Other materials were much better adapted for such situations, as slate, glass, and timber, which were not liable to damage from a corrosive atmosphere.

Mr. Gregory, President, thought that the Meeting would agree with him that this Paper was a highly suggestive one, from which all might learn a valuable lesson, while it was marked by that practical philosophy which might be expected from its Author. The great lesson to be learnt from the Paper was to look a little deeper than the mere surface for the causes of those actions with which engineers had to contend. With regard to the operation of

water in the deterioration of materials, the suggestions of the Paper were very useful, pointing out as they did that condition of dampness which was the most injurious, and the principles upon which protection should be applied. Again, the permanence of materials which suffered from a damp atmosphere, when exposed in an air generally dry, was well illustrated by the durability of the tinned roof coverings common in Geneva and St. Petersburg, and, as many of them knew, in Canada. As engineers they were accustomed to trace the analogy between the elements of animal action and the combustion which worked the steam engine; but the analogy pointed out between decomposition and combustion would probably be new to most of them, and might afford the key to many of the phenomena of decay, which had hitherto been inadequately studied, and which for that reason had not been traced to their true causes.

He alluded to these as simple illustrations of the valuable lessons to be derived from this Paper, (discursive as it might at first appear), by pondering well the observations that had been made by a man known not to be a mere theorist, but to have well applied theory to practice. He was sure all had heard with satisfaction that the Britannia Bridge, which was not only a fine application of wrought iron to structural purposes, but a monument of their greatly-lamented Past-President, Mr. Robert Stephenson, was not undergoing anything like decay. He did not think any amount of watching over structures of that sort could be vain and superfluous; because he was sure, as had been admitted, that structures of wrought-iron plates, unless very carefully watched and protected, possessed in themselves the elements of serious deterioration, and ultimately of danger. Panics were apt to arise in this country, and he thought that this failing extended sometimes to the profession of engineers. Perhaps at one time they were driven into the use of wrought iron with rather unreasonable haste, from a fear of cast iron, arising from its undue or injudicious use in a few instances where it was expected to do more than it could, and where it consequently failed. Every now and then the question of the comparison of wrought iron and cast iron cropped up in the Institution; and he was glad to hear a man of the experience of Dr. Pole raising a warning voice against the indiscriminate use of wrought iron, however great its popularity and its real value and facility of application, unless it were applied under conditions where its permanent security could be insured or watched over, to save it from greater failures than had attended the use of its neglected predecessor, cast iron.

He might have ventured to offer a few illustrations of some of the valuable truths brought forward in the Paper, but he felt that these would suggest themselves to those who would study the Paper

itself; and he thought he might, on behalf of the Institution, express the hope that this Paper would be supplemented by others of a similar character.

Mr. Gregory, President, observed that, as the last business meeting before the recess had now arrived, he might perhaps be allowed to say that during this session, 1867-8, the increase of members had been certainly beyond what might have been expected, in times not the most brilliant or encouraging for the engineer. There had been an increase of 45 Members, and 105 Associates. The Register of the Institution now contained the names of 16 Honorary Members, 641 Members, 914 Associates, and 123 Students; in all, 1,694 as against a total of 1,449 of the various classes at the same date last year, including, at that time, 20 Honorary Members, 596 Members, 834 Associates, and 4 Graduates. The class of Students had been created during the past year. The Council took great interest in the advance of that class, and if the Students had not had their own evening meetings during the past session, it was not the fault of the Council. Let him remind those Students who were present, that the Council, as they had announced at the beginning of the session, were anxious to see them bringing their Papers forward for discussion among themselves in that room, under the eye of some one deputed from time to time to preside over the meetings, not actually as a teacher, but to take care that those discussions were conducted in such a way as to be for their benefit and advantage. The Council hoped that, at an early period after the recess, the Students would have sent in several Papers, so that they might have the pleasure of seeing the Students meeting, like themselves, during the next year, and strengthening their powers of thought by the discussion of professional subjects, he would not say in that room as it was then, but in that room very much improved and enlarged.

May 19, 1868.

CHARLES HUTTON GREGORY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Thomas Login, William Teasdel, and Edward Williams, as Members; Henry Samuel Ellis, Charles Higgins, William Hurst, Samuel Joseph Mackie, and John Palmer Smythies, as Associates.

It was announced that the following Candidate, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, a Student of the Institution:—NICHOLAS CHARLES SZERELMEY.

The discussion upon the Paper, No. 1,179, "On the Durability of Materials," was continued throughout the evening, to the exclusion of any other subject.

May 26, 1868.

The Session was concluded by a CONVERSAZIONE, at which the President received the Members of the Institution and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited an interesting collection of mechanical models.

APPENDIX TO VOL. XXVII.

MEMOIRS.

Dr. MICHAEL FARADAY was born at Newington, in Surrey, on the 22nd of September, 1791. His father, a Yorkshire blacksmith, was not rich enough to afford his son a better education than could be obtained at a common day-school in the neighbourhood; but he acquired, from such books as fell in his way, so much information of a general character as deeply interested him, and induced a fondness for reading, at the same time that it quickened those habits of careful observation which were natural to his disposition. When thirteen years of age, he was apprenticed to Mr. Riebau, of Blandford-street, a bookseller and binder. About this time, in the intervals of business, he made an electrical jar out of a physic-bottle, and then a complete electrical-machine with a proper cylinder, which remained long afterwards the useful companion and assistant of the famous philosopher. Towards the close of the year 1812, Mr. Dance, a Member of the Royal Institution who frequented Mr. Riebau's shop, gave him tickets to the last four of a course of lectures on chemistry which Sir Humphry Davy was delivering in Albemarle Street. He took notes, and afterwards wrote them out more fairly in a quarto volume. His desire to escape from trade, which he thought vicious and selfish, and to enter into the service of science, which he imagined made its pursuers amiable and liberal, induced him at last to write to Sir Humphry Davy, expressing his wishes, and a hope that, if an opportunity offered, his views might be favourably entertained; at the same time he sent the notes taken at the lectures previously referred to. Sir Humphry Davy requested to see him, and early in March, 1813, procured him the situation of chemical assistant in the laboratory of the Royal Institution. In October of the same year he accompanied Sir Humphry Davy to France, Italy, Switzerland, &c., as amanuensis and assistant in chemical experiments, and resumed his situation in the Royal Institution when he returned to England in April, 1815. In 1820 he published his discovery of the chloride of carbon; and in October of the same year he commenced his investigations on the relation of electricity and magnetism, the discovery of which had been announced by Œrsted. In the following year he published his discovery of "New Electro-Magnetic Motions," to which he added "A Theory of Magnetism,"

in the "Quarterly Journal of Science." In 1823 the condensation of chlorine into a liquid was first effected by him, and an account of his experiments was published in the "Philosophical Transactions," with a note by Davy "On the Condensation of Muriatic Gas into the Liquid Form." This year he was elected Corresponding Member of the Academy of Sciences of Paris. On the 8th of January, 1824, he was elected a Fellow of the Royal Society, mainly through the instrumentality of the late Richard Phillips, the chemist; and in 1829 he was appointed by the Royal Society to deliver the Bakerian Lecture, the subject being "On the Manufacture of Glass for Optical Purposes." In the same year he was appointed Chemical Lecturer at the Royal Military Academy at Woolwich, a post he held till 1842. In 1831 his first paper on the subject of electricity appeared in the "Philosophical Transactions," describing his experimental studies of the science; and from that time for many years the "Philosophical Transactions" annually contained papers by him, giving the method and result of his investigations. These papers, with some others contributed to scientific journals on the same subject, were subsequently collected at different intervals in three volumes under the title of "Experimental Researches in Electricity." The first volume appeared in 1839, and contained the contributions to the "Philosophical Transactions" up to that date—in all, fourteen series. The second volume was published in 1844, and the third in 1855. These researches in electricity are, beyond all doubt, the choicest series of examples of pure induction to be found in the English language. He established the identity of the forces manifested in the phenomena known as electrical, galvanic, and magnetic; he ascertained with exactness the laws of magnetic action; and he determined its correlation with the other primal forces of the natural world. The high character of these researches led the University of Oxford, in 1832, on the first occasion of the meeting of the British Association at the University, to confer on him the honorary degree of Doctor of Civil Law. Meanwhile the chair of chemistry in the Royal Institution was founded in 1833 by Mr. Fuller, and at his express desire Dr. Faraday was nominated the first Fullerian Professor. In 1835 Lord Melbourne's government recognised the importance of his scientific discoveries by granting him a pension of £300 per annum, and in the following year he was appointed scientific adviser on lights to the Trinity House, and subsequently to the Board of Trade. From this time many honours were conferred upon him. He was raised from the position of Corresponding Member to be one of the eight Foreign Associates of the Academy of Sciences of Paris. The Royal Society conferred on him, in 1846, its own medal and the Rumford medal for his discovery of diamagnetism and the influence of magnetism upon light.

He was a Commander of the Legion of Honour, a Knight of the Prussian Order of Merit, of the Italian Order of St. Maurice and Lazarus, and a member of numerous scientific bodies on the continents of Europe and America. He was elected an Honorary Member of the Institution of Civil Engineers on the 26th of June, 1838. As a lecturer on science, Dr. Faraday was without an equal. At the table in the theatre of the Royal Institution, with his beautifully-devised apparatus around him, he was perfectly at home and at ease. The first words which fell from his lips conveyed to all an impression of thorough earnestness, an intense desire to know, and to impart the knowledge he had acquired. His language was always simple. He sought to reach the mind of every hearer through more senses than one. He never told his listeners of an experiment, he always showed it to them, however simple and well-known. No man was ever more entirely unselfish, or more entirely beloved. Modest, truthful, candid, he had the true spirit of a philosopher and a Christian. In 1858 the Queen allotted him a residence at Hampton Court, between which and Albemarle Street he spent the last years of his life, and there he died on the 25th of August, 1867.

The Right Honourable William Parsons, third EARL OF ROSSE, was born at York, on the 17th of June, 1800. The elementary part of his education was acquired under his father's roof; and in the year 1818 he entered Trinity College, Dublin. After a successful course of study he, in the following year, migrated to Magdalen College, Oxford, where he took his degree of B.A. in 1822, obtaining a first class in mathematical honours. As Lord Oxmantown he represented King's County in the House of Commons from 1821 till the end of the first reformed Parliament; and although he seldom took part in the debates, he proved an excellent man of business on Committees. From this time he devoted himself more closely to philosophical pursuits.

Besides his acquirements as an astronomer and a mechanician, he was a political economist of a high order, and devoted much attention to the question of national education. He was a good chemist, and possessed a large amount of military, nautical, and engineering knowledge. As evidence of this it may be mentioned that he had formed the conception of armoured ships some years before the Crimean war, and had shown that vessels of no great tonnage could carry a sheathing of 4 inch plates, which would be proof against the 32-pounder, the normal gun of the time.

But it was as a constructor of reflecting telescopes[1] that Lord

[1] The description of these improvements has been principally taken from the "Proceedings of the Royal Society," vol. xvi., p. xxxviii.

Rosse was most celebrated. To obtain speculum metal of the highest standard, he combined four equivalents of copper and one of tin. The resulting compound is very brilliant, and resists tarnish far better than if there be a slight excess of either ingredient: but it is nearly the most intractable of all materials—harder than steel, more brittle than glass, and flying in pieces with any sudden change of temperature. In consequence, all large specula which had been previously made contained a larger proportion of copper than the above, to ensure the necessary toughness. At first he combined a central disc with annular zones two or three inches broad, and ground and polished them spherical; and by a fit adjustment, each, beginning at the centre, was drawn back till their foci coincided. Yet the complexity of the arrangement, and its liability to change with temperature were weighty objections, and he was led to devise another plan. In polishing these rings he found the outer ones too large for hand-work, and made, in 1828, a machine which gave a rectilinear motion to the polisher while the speculum revolved. This was only expected to produce a spherical figure; but it caused rings and other irregularities, which he saw would be corrected by adding a second eccentric, giving a lateral motion to the polisher. This changed its course into a curve which might be varied from a right line to an ellipse almost circular. This had the desired effect; but on watching its action, he saw that it would give what was the great desideratum, a change of curvature from the centre to the circumference, which could be varied at pleasure, and therefore could be made to give a true aplanatic figure. The machine so altered was subsequently employed, with only one change of any importance, which was a means of setting the speculum vertical while on the polishing machine, and testing it by a terrestrial mark. This much facilitates the obtaining a perfect figure. He met the difficulty of obtaining a large speculum, by making a strong frame of a peculiar brass, which has the same expansion as fine speculum-metal, and soldering on its front thin plates of the latter, cast on as large a scale as possible, and closely fitting them on the edges. From what has been said of the properties of this alloy, it may be judged how much mechanical skill the process required; but he succeeded in making a 3-feet speculum. It was very light and strong, and defined perfectly, except that, with large stars, the diffraction at the joints produced four minute rays. For those below the fifth magnitude, and for fainter objects, this defect is insensible; and Lord Rosse believed that in this way only would it be possible to attain the extreme limit of telescopic vision. The construction is stronger than the solid speculum, with a third of its weight; and the cellular distribution of the greater part of the mass enables it to assume the temperature of the atmosphere

far more rapidly. Meanwhile he was led to an important improvement in casting speculum metal. When the melted alloy is poured into a mould, the surfaces in contact with the mould harden, while the interior of the mass is still fluid; this cools in its turn, and, in contracting, exerts a powerful drag on the outer crust, which gives way, and the whole is shivered. Besides, if the solidification is gradual, the mass assumes a crystalline character, which gives it, when polished, a mottled surface. These difficulties were met by forming the bottom of the mould of iron, the sides of sand, and by leaving the top open. The metal in contact with the iron congealed almost in an instant, the sides of the speculum more slowly, as the sand is a worse conductor than the iron, the upper part remaining fluid longest; so that the contraction occurred chiefly at the back of the speculum, where it did no harm, while the front presented a layer of uniform and comparatively tough material; but this was a little more liable to tarnish than that which was cooled slowly. He found, however, that speculum metal, like copper, absorbs in fusion a large quantity of oxygen, much of which it gives out on becoming solid. This always produces microscopic pores, and causes bubbles and cavities, which are found even when no air is entangled in the pouring. To give the gas a free escape, he made the bottom of the mould of hoop-iron, placed on edge and packed so closely that it retained the metal, but was pervious to the gas; and so successful was the experiment, that by the summer of the year 1839 he had succeeded in making a solid 3-feet speculum. In April, 1842, he had made a perfect cast of a 6-feet speculum, which was accidentally broken after being partly ground; and finally, in February, 1845, he completed an instrument 52 feet in length and 7 feet in diameter, having a 6-feet speculum. The tube is supported at its lower extremity by a massive universal joint. It is counterpoised by weights, which are constrained to move in a circular arc nearly coinciding with the curve of equilibrium; and a steady strain is kept upon the suspending-chain by means of three weights attached to levers, which successively come into play as the tube approaches the zenith and passes north beyond it. A chain connects the levers at the proper intervals and the tube with them; and as the tube descends, each lever takes its place successively in a deep recess in the ground, the chain subsiding into a heap. The motion in right ascension is by a rack, the extremity of which bears by rollers on a circular arc of 40-feet radius. This rack is connected with the tube by a pinion, and the pinion is acted upon by an endless screw driven by a pulley, which pulley is driven by a band from a potter's wheel attached to the lower end of the tube. For polar distances there is a circle, 18-inches radius, at the lower end of the tube, furnished with a spirit-level; but for finding objects there is an index of

6-feet radius connected with the transverse axis of the universal joint. By means of three galleries provision is made for enabling the observer to reach the eye-piece in every position of the telescope. Every part of the structure is of great strength, and the telescope is perfectly steady even in a high wind.

By means of this magnificent instrument many of the nebulæ, previously seen merely as luminous patches, were resolved into stars, and in others a spiral form and arrangement were detected. Its cost was about £30,000, and its completion was a work of seventeen years. It deserves notice that all this massive work was executed in Lord Rosse's laboratory at Birr Castle, and that he had so thoroughly considered the whole, that in no instance was it found necessary to deviate from the drawings which had been prepared.

In 1836 he married the eldest daughter and co-heir of the late Mr. John Warner Field, of Heaton Hall, Yorkshire, by whom he leaves three sons. He succeeded to the earldom in 1841, and four years later was elected a representative peer of Ireland in the House of Lords. He had been Lord-lieutenant of King's County since 1831, and Colonel of the King's County Militia from 1834. Lord Rosse was a Fellow of the Royal Society, of which he was President from 1848 to 1854. In 1842 the University of Cambridge conferred on him the degree of LL.D., and in the following year he presided over the meeting of the British Association at Cork. In 1853 he was elected one of the members of the Imperial Academy of Sciences at St. Petersburg; and he was made a Knight of the Legion of Honour by the Emperor of the French in 1855. He was also a Knight of St. Patrick, and a member of many learned societies on the Continent. Since 1862 he had filled the post of Chancellor of the University of Dublin. His connection with the Institution of Civil Engineers dated from the 5th of June, 1849, when he was elected an Honorary Member.

He died on the 31st of October, 1867, sinking under the effect of the removal of a tumour caused by a sprain of the knee.

Mr. ALEXANDER GIBB, the only son of Mr. John Gibb, C.E., was born at Larbert, in Stirlingshire, on the 21st of September, 1804. His father having removed to Aberdeen, he received his early education at the Grammar School, and completed it at the Marischal College of that city. Having finished his studies, he entered the office of his father's friend, Mr. Telford, with whom he enjoyed the advantage of living during the period of his apprenticeship, and a friendship sprung up between him and his distinguished master which lasted till the death of the latter.

On the completion of his apprenticeship Mr. Gibb returned to Aberdeen, and entered into partnership with his father, who was at that time contracting for public works. For some years they were principally engaged in the erection of lighthouses for the Commissioners of Northern Lights, under the direction of Mr. Robert Stevenson. During this period Mr. Gibb personally superintended the erection of the lighthouse on Cape Wrath.

Between the years 1827 and 1829 he was employed with his father in the construction of a large bridge over the River Don, near Aberdeen. Shortly after they undertook the formation of a wet dock and other works at the Aberdeen Harbour, under the direction of Mr. Telford, about which time he designed the first dredging machine ever used in the harbour of Aberdeen. When these were finished they were intrusted with the erection of the Dean Bridge, in Edinburgh, and the manner in which this work was executed called forth the warmest praise both from Mr. Telford and from the civil authorities. In 1835 they completed the Jamaica Street Bridge, in Glasgow, a year before the expiration of the contract, on which occasion they were presented with two handsome pieces of plate. In 1836, Mr. Gibb and his father undertook the building of the Victoria Bridge over the Wear, on the line of the Durham Junction Railway, under Mr. Harrison (Vice-President Inst. C.E.).

Shortly after the completion of this bridge, remarkable for its height and large spans, they entered into a contract for the construction of a portion of the Edinburgh and Glasgow Railway at Almond Valley, under Mr. Miller, which was the last work the firm of John Gibb and Son executed as contractors.

In 1842 Mr. Gibb again returned to Aberdeen, and there occupied himself in the practice of his profession as a civil engineer. During the stormy days of railway enterprise he planned and carried out many important lines in the north of Scotland, and, subsequently to his father's death, was Engineer both of the Aberdeen Railway and of the Great North of Scotland Railway. He devoted himself to his business with untiring energy and perseverance, and accomplished an amount of work which few men would have attempted. The estimate in which his practical sagacity was held by those competent to judge may be gathered from the opinion of Sir William Cubitt, who, in writing in 1844 to the Provisional Committee of the Aberdeen Railway Company, said, "It is due to Mr. Alexander Gibb, your Engineer, to express the high opinion I entertain of the talent and care displayed by him in the investigation of, and laying down through a very difficult country, the various lines of railway which came under my notice, and that the greatest credit is due to him for producing a line without a tunnel, with gradients in no case steeper than 1 in 100,

and with no curves with less than half a mile radius; and although after my examination of the country I caused two or three alternative lines and deviations in different places to be levelled with a view to improvement, I have been obliged to revert again to the line as laid down by your Engineer, which is the strongest proof I can adduce of the care taken by him in the selection of the lines." Mr. Gibb remained Engineer of the Great North of Scotland Railway and its numerous branches up to the time of his death.

In addition to his business as Engineer, he carried on the quarrying of granite in the vicinity of Aberdeen. His father had been the first to introduce the use of this valuable stone in the construction of public works, and the business was further developed by him. He was the lessee of the well-known Rubislaw Quarries, near Aberdeen; and when the British Association met in Aberdeen, under the Presidency of the late Prince Consort, Mr. Gibb read a Paper on this subject.

During the last three years of his life he took a lively interest in the large works which his son, Mr. Easton Gibb, constructed, under Mr. James Simpson (Past President Inst. C.E.), for the purpose of supplying Aberdeen with water, and although not himself connected with them, his valuable advice was often had recourse to.

He was frequently a Town Councillor, and once Harbour Master for the city. He was also an elder of the Free Church of Scotland, in which he took a lively interest. But perhaps the recollection of his kindly disposition and manners will do more than anything else to endear his memory. He was held in much respect, and was a most considerate man to all about him, and especially to those under him.

Mr. Gibb was elected a Member of the Institution on the 9th of February, 1830, and died at his residence, Willowbank, Aberdeen, on the 8th of August, 1867, after an illness of a few days, aged sixty-three years.

Mr. WILLIAM GILBERT GINTY was born in Ireland about the year 1820. His father was an architect, and the son, when a youth, joined the Ordnance Survey of Ireland, and remained connected with it and that of England for eight years. Mr. W. G. Ginty was also employed on the Tithe Commission Survey, and was afterwards, for five years, engaged in works connected with the Lancashire and Yorkshire Railway, under Mr. Hawkshaw (Past President Inst. C.E.). He was then appointed Engineer and Manager to the Hydro-Carbon Gas Company; and rendered valuable service as Honorary Secretary to the Manchester Athenæum.

The Baron de Maua, who had established the Imperial Gas Works at Rio de Janeiro, under concession from the Brazilian Government, required a general manager. Mr. Ginty was selected in 1854—as one possessing the requisite engineering and administrative talent—and his judicious and energetic management raised the undertaking into a most prosperous state, both as regarded efficiency and pecuniary success; and on its establishment as a public Company in England, in 1865, Mr. Ginty was retained as Manager.

In 1857 Mr. Ginty designed and subsequently constructed a canal 40 feet wide and about 1,400 yards in length, for the conveyance of market produce from the bay at the Aterrado Bridge to the public market. It was spanned by several iron bridges; the sides were lined with walls of rubble masonry, and the depth of water at high water was 8 feet. By this work a malaria-breeding swamp was removed and the sanatory condition of the city much improved.

In 1861 the organization and administration of the Tijuca Railway, from Rio to Tijuca Sierra, were confided to Mr. Ginty, on the Company by which it had been made falling into difficulties; and it was owing to his tact and perseverance that the prejudices against the locomotive on this street tramway were overcome.

In 1865, as Manager of the Company, he entered into a contract with the Brazilian Government for the construction of a carriage-road of about 5,150 yards in length, in continuation of the tramway up the mountain to the Praça de Boa Vista at Tijuca. This road was approaching completion at the time of his death.

The engineering skill, practical good sense, and sound judgment of Mr. Ginty were found valuable in the sanatory arrangement of the Palace grounds for the Emperor, and in numerous consultations with other Engineers on any public engineering project connected with water supply, sewerage, dock and warehouse accommodation; and in May, 1860, the Emperor of Brazil recognized his public services by conferring upon him the honour of knighthood in the Brazilian Order of the Rose.

Mr. Ginty was elected a Member of the Institution on the 5th of February, 1861, and died suddenly of paralysis of the brain succeeding apoplexy on the 13th July, 1866. He was greatly respected for his straightforward energy and honourable conduct in his profession, whilst he gained the respect and esteem of those with whom he was associated by his good feeling, kindliness of heart, and sterling integrity, combined with bright intelligence, and sparkling wit.

Mr. ROBERT HAWTHORN was the eldest son of Robert Hawthorn, who for upwards of fifty years was Engineer to the owners

of Walbottle Colliery, near Newcastle-upon-Tyne. To old Robert Hawthorn, the late George Stephenson was indebted for much valuable mechanical information, which he afterwards successfully applied to work intrusted to him for execution, and when he became a resident at Killingworth, he made many journeys to Walbottle to obtain the benefit of Mr. Hawthorn's advice.

Though really the servant of the owners of Walbottle Colliery, Robert Hawthorn, senior, was frequently consulted on engineering questions, and more than once by the Caledonian Canal Company on important features in connection with their works.

The subject of this Memoir was born on the 13th of June, 1796, in a cottage on the north side of Dewley Burn, near Walbottle. The rudiments of his education were acquired at country village schools, first under a master named Henry Milburn, at Penny Hill, near Dissington, till about the year 1806; he was then placed at a school under the rector of Newburn; and later on, he went to Walbottle village school, to which a person named William Mack had been appointed from the Rothbury Grammar School, and to him Robert Hawthorn and his younger brothers were chiefly indebted for the education they received.

His apprenticeship to the owners of Walbottle Colliery commenced under the management of Mr. Thomas Ramsay, and the latter part of it under Mr. William Potter, though he was really under the tuition of his own father, than whom no one at that period was more competent to impart a thoroughly practical knowledge of mechanical engineering.

Toward the end of his apprenticeship he was intrusted with the erection of a small condensing engine, constructed under his father's direction at Walbottle, for Mr. Potter's brewery at Forth Banks, Newcastle-upon-Tyne. After this, in 1816, he erected a pumping-engine at Brinkburn Colliery, which long afterwards was a standard reference of his ability. On his return from that work, having completed his apprenticeship in January, 1817, he became the tenant of premises behind Mr. Potter's brewery already referred to, where he commenced business as a manufacturer of steam-engines, millwork, and other machinery. At this time, besides himself, only four workmen were employed, who afterwards became foremen of departments, and who lived and died in his service.

In 1818 his brother William joined the works as an assistant and working foreman. During this year orders for machinery rapidly increased, rendering more space necessary; and in 1819 a piece of ground on a sloping bank side was purchased; it was levelled and prepared for building on by the master and his workmen after the regular working hours, and the workshop erected on it yet remains, and forms a small fraction of the present erections.

In 1820 William Hawthorn became his partner, and the indi-

vidual career of Robert Hawthorn was merged in that of the firm of R. and W. Hawthorn, in which he uninterruptedly continued the senior partner, his brother William being the only other partner. This year the firm introduced a self-acting crane to deliver ballast from ships, and put one up for Mr. J. S. Bulman, at St. Anthony's Quay, on the Tyne. In 1824 the firm supplied a 50-horse power engine to Messrs. Isaac, Cookson, & Co.'s glass-works, of such excellent workmanship that for many years it was held up as an object of admiration to visitors, and it still does duty. In the same year they also introduced a self-acting steam travelling-crane, and erected one on Hebburn Quay for the late William Rea.

Locomotive engines were first made by the firm in 1831, and this manufacture has been an extensive part of the business up to this time.

In 1832 Robert Hawthorn invented and arranged a new slide rule for the use of engineers, which was soon generally adopted in the trade. In 1834 the first Cornish pumping engine made in this district was manufactured by them for the Newcastle Subscription Water Company; and in 1835 they applied fixed eccentrics in a locomotive engine supplied to the Newcastle and Carlisle Railway Companies, and used at the opening of the line. This invention was afterwards adopted by other engine builders throughout this and other countries.

Subsequently, the firm continued to enlarge its business, and was for many years extensively employed in the construction of all kinds of steam engines for pumping water, for driving machinery, for locomotive and marine purposes, both in England and abroad.

Mr. Hawthorn was elected a Member of the Institution of Civil Engineers on the 13th of February, 1839. He died on the 26th of June, 1867, and his remains were interred in the churchyard of Newburn, near Walbottle, on the 2nd July, in the presence of a large concourse of the operatives employed in many of the Newcastle engineering establishments, who spontaneously attended to manifest their respect for the deceased.

Mr. EDWARD HUMPHRYS was born near Penzance, in the year 1808, and was removed to Bristol in 1810. Originally destined for a harness and boot and shoe maker, he served in that capacity for three years; but, finding the occupation uncongenial, was regularly apprenticed as an engineer to his elder brother Francis, in Liverpool. From thence he removed with him to South Wales, and for two and a half years was engaged as mechanical Engineer at the Nant-y-glo Iron Works, in the construction of locomotive

and other engines; after which he was engaged by the London and Dublin Steam Navigation Company, superintending the machinery of steam vessels in Dublin, which engagement he closed to come to London. The first work on which he was engaged in the metropolis was at Hammersmith, where he erected some machinery for drawing lead pipes. Subsequently he entered the service of Messrs. Mainwaring and Co., of Lambeth, as an ordinary workman, but speedily rose to the rank of foreman. While he was with them he superintended the erection of several steam engines, together with pumping and other machinery. For a short time he was in the employment of Messrs. Penn, of Greenwich, and of Messrs. Hall, of Dartford, and eventually entered on business in a small way on his own account at Lambeth, where he remained six years. Whilst here he constructed the first marine engines he made. These were placed on board the small river boats 'Swallow' and 'Don Juan;' but they were not considered very successful. He also produced the beautiful stationary engine, on Wolff's, or the compound principle, for the Polytechnic Institution. But as the business was not profitable, he, in 1811, became manager for Messrs. Rennie, at their works in Holland Street, Blackfriars. It was while at Messrs. Rennie's that Mr. Humphrys introduced the circular ring for taking off the pressure from the back of slide valves, and the India-rubber disc valves for air pumps. In 1850 his services were transferred to the Messrs. Nasmyth, of Patricroft, and shortly after he became Chief Engineer of Woolwich Dockyard. This post he resigned in 1852, when he entered into partnership with Messrs. Tennant and Dykes, and with them established the marine engine works at Deptford Pier.

Mr. Humphrys, by example and precept, discountenanced at all times apathy and indolence. He drew his own plans, managed his own works, and was always the first man in the factory in the morning, and the last out at night. He put forth his best energies to make a complete success of the compound marine screw engine, and he made considerable headway. By improvements in superheating, surface-condensing, and expansion, he managed to work down to $2\frac{1}{4}$ lb. of coal per indicated horse power per hour; but as these economical engines broke down, some of them had to be replaced by single engines. Notwithstanding, his career may be described as a steady, onward march towards the highest point of professional prosperity, and which point, at the time of his death, he had well-nigh gained.

Mr. Humphrys was the author of several papers in the Transactions of the Institution of Naval Architects. He was elected a Member of the Institution of Civil Engineers on the 6th of June, 1848; and died at Nice on the 13th of May, 1867, after an illness extending over several months.

Mr. PARKIN JEFFCOCK, the second child and eldest son of John and Catherine Jeffcock, was born at Cowley Manor, near Sheffield, on the 27th of October, 1829. In 1841 he entered the Grange School, near Sunderland, where he was noted rather for diligence and application to his studies than for any superior degree of talent. Intended originally for holy orders, scruples as to his fitness for that responsible office overcame him within a few days of his going up to Oriel College, Oxford, for his matriculation, and in the autumn of 1848 he entered the then existing College of Civil Engineers at Putney, under the principalship of the Rev. M. Cowie. During the two years he remained there, he received prizes of books for proficiency in French and German, and for an outline drawing of the college stationary engine. In the autumn of 1850 he was articled to Mr. George Hunter, of Belmont Hall, near Durham, a north country colliery viewer of great experience. Here he had ample opportunities of seeing the general working of coal mines according to the north-country system, and of examining in detail the various special contrivances which critical circumstances and emergencies call into requisition. On Mr. Hunter's sudden death in 1851, he again was articled to Mr. J. T. Woodhouse, of Overseal, with whom, on the 1st of January, 1857, he became associated in partnership.

Mr. Jeffcock was remarkable for his great application and industry. He opened out the whole of the works at the Wharncliffe Silkstone Colliery; carried out the alterations in the Shipley, Denby, Swanwick, Maria Granville, and other fiery collieries, and was largely occupied in shaft-sinking, in the construction of branch colliery railways, and in the erection of steam engines and machinery incidental to colliery operations. He was an early riser, and the amount of work, both professional and on public and charitable accounts, which he got through was immense. A deeply religious man, he was by preference and conviction a member of the Church of England; and died churchwarden of the parish of Duffield, near Derby, in which he took real interest. His Sundays specially were spent in Christian work—the most noticeable being a class of boys, which he held at the Sunday school in the afternoon; and a Bible lecture in the evening, for young colliers and others, for whose benefit he devoted some hours of his day of rest, for nearly fifteen years continuously. His almsgiving was profuse. Beyond all praise was the modest, unobtrusive, but untiring devotion of his few leisure hours to the sick poor. After a day of incessant fatigue he would, instead of going home, proceed to the cottage of a sick or dying person to minister comfort.

Six feet in height, he was a good rider, and a good shot. His personal endurance and bravery, however, were seen to the truest

advantage when linked with his Christian philanthropy in those harrowing scenes which from time to time cast a gloom over the life of a Mining Engineer. For instance, at the accidents at Stavely, Swanwick, and Clay Cross Colliery, where he was nearly drowned, he freely exposed himself in his attempts to recover the living pent up in the recesses and the dead. It was while engaged on such a work that he lost his life at the Oaks Colliery, Barnsley, on the morning of the 13th of December, 1866. An explosion on the previous day had killed three hundred men; and it was while with an exploring party, and after he had been in the pit ten hours continuously, that a second explosion occurred, destroying him and the band of thirty explorers still in the ruins. His body was recovered on the 5th of October, 1867, and he was buried at Ecclesfield, near Sheffield, two days afterwards.

Mr. Jeffcock was elected a Member of the Institution of Civil Engineers on the 18th of May 1858. He was also a Member of the Society of Mechanical Engineers, a Member of the Society of Engineers, and a Fellow of the Geological Society.

Mr. GEORGE MAY was born at Inverness, on the 14th of September, 1805. He was educated at the Inverness Academy, and afterwards at King's College, Aberdeen. In 1823 he was entered as an apprentice with the late Mr. Telford, and remained with him until September, 1827, when he was appointed cashier on the Caledonian Canal at Inverness. He continued to hold this office until the summer of 1829, when he became Engineer and Superintendent of the Caledonian Canal, to which the superintendence of the Crinan Canal was afterwards added. These appointments he held for the long period of thirty-eight years, faithfully and ably discharging his duties until within a few weeks of his death, which took place at Inverness on the 28th of August, 1867.

Apart from his professional attainments, Mr. May was a man of varied talent and information, of correct taste, and strong, clear understanding, although great diffidence concealed to ordinary observers his higher merits. Kindness and simplicity of character were in him united to a high sense of honour and inflexible integrity. Early in life, by the death of his father, a numerous family, young and helpless, were thrown upon his care, and the manner in which he fulfilled that sacred trust, the sacrifices he made, and the depth of feeling and attachment he displayed, have never been surpassed.

Mr. May was one of the earlier members of the Institution of Civil Engineers, having joined it as an Associate on the 30th of

March, 1824; and he was transferred to the class of Members on the 26th December, 1837.

M. AUGUSTE PERDONNET was of Swiss origin, and was regularly educated as a Civil Engineer in the *Ecole des Mines*, at Paris. On leaving, in 1822, he pursued the study of mining and metallurgy with his friend M. Coste, while on a visit to England, and they together published their observations under the title of *Voyage Métallurgique*. The manufacture of iron by coal had at this time made but slight progress in France, although extensively practised in England. M. Perdonnet saw the advantages of the system, and boldly advocated its adoption, which, had it been followed, would have accelerated the transformation of the iron industry in France. It was also while he was in England that he became convinced that public works could only receive their proper development from a large participation of private industry in their execution and working. The doctrines of social economy propagated in 1830 by men in general educated at the *Ecole Polytechnique* were only accepted after long discussions, so far as related to the serious question of accomplishing public services by large associations. To further these views M. Perdonnet, with his friends, established a debating club, with which he associated the entire though small body of Civil Engineers, among whom he acquired considerable influence. At this time it was urged that there was no room for the exercise of the profession of civil engineering, on the ground that it was a tentative system, and trespassed on the domain of the government engineers; and this doctrine would have probably triumphed had it not been for the discovery and inauguration of railways. The development of these M. Perdonnet furthered with the greatest zeal, and it was by this happy circumstance that the profession acquired a standing. But besides the old pupils of the *Ecole Polytechnique* and some other self-made engineers, so few men had received a sufficiently scientific education to meet the requirements of the new art, that it would have become necessary to call in foreign engineers. However, M. Perdonnet, who had been meanwhile called upon to join the *Ecole Centrale* as its director, considered it a suitable means for forming engineers fit to undertake public works granted to companies, and established a course of lectures on the construction of railways. His *Traité des Chemins de fer*, and *Portefeuille de l'Ingénieur*, embody at once his learned lectures, and the universal experience of engineers. For when it was necessary to gather information, to control a new method, or to make known and apply a new discovery, he spared neither time nor expense. Received everywhere as an accomplished master, he was able to gather together precise data respect-

ing all the facts which constantly arose in the still novel industry of railways; and he contributed almost more than any one else in France to its rapid extension, by the exact information he published, by his impartial criticisms, and by his enlightened judgment. One incident will serve to show the devotion with which he accomplished his duties, and his desire to justify the confidence he inspired. When the completion of the railway on the left bank of the Seine from Paris to Versailles was suspended from lack of capital, a subvention was demanded from the Government. A schedule of the probable expenses was prepared by M. Perdonnet, and was accepted by the Administration; but the Commission of the Chamber of Deputies hesitated, despite the care with which the schedule had been prepared. One of the members knowing that M. Perdonnet was rich, having asked him if he would guarantee the sum by his private fortune, the latter did not hesitate to undertake to do so,—an offer which, though not accepted by the Commission, had a decisive influence on the favourable decision which was arrived at.

Besides being director of the *Ecole Imperiale Centrale des Arts et Manufactures* and President of the *Association Polytechnique*, M. Perdonnet was for many years administrator and director of the *Chemin de fer de l'Est*, and retained this post until his death. He was also a director of the *Chemin de fer de l'Ouest Suisse*. He was President of the Society of Civil Engineers of France for the year 1851; and on retiring from the occupation of the chair, was elected Honorary President. He was elected a Member of the Institution of Civil Engineers on the 4th of December, 1860, and died at Cannes on the 27th of September, 1867, of a dropsical affection of several years' standing, and which finally attacked the brain.

Mr. JOHN BETHELL, only brother of Lord Westbury, late Lord Chancellor, was the second son of Dr. Bethell, of Clifton, and was educated for the common law bar. He subsequently practised as a solicitor in London, and in 1833 became interested in a factory for making screws, bolts, and rivets, by Samuel Wright's machinery, for the improvement of which he took out his first patent in 1834. From Dr. Neill Arnott, and the late Dr. Ure, he acquired sound views of physics and chemistry; and in 1835 he patented a complete system of diving-apparatus, consisting of an air-tight dress and helmet, to which air is supplied of a density proportionate to the depth descended by the diver, together with an arrangement of available air-bladders and weights which enable him to rise or sink in the water. On July the 11th, 1838, Mr. Bethell took out a patent for his process of preserving timber from decay and from the

attacks of insects and worms, by impregnating it with creosote oil. This invention has been adopted on a large scale both in England and on the Continent, notwithstanding there has been much diversity of opinion as to its value. It renders timber brittle, and it is no protection against white ants. Even on the score of durability the question has been raised, whether the compound interest of the money spent in creosoting sleepers does not amount to more than the value of the process. In marine works, however, creosoting is almost indispensable, as it forms the only known protection against the ravages of the teredo and the limnoria terebrans. By this process fir timber can be injected with 10 lbs. of oil per cubic foot, and beech timber with nearly 20 lbs. He took his idea of preserving wood by creosote from the embalming of mummies, the creosote having the property of coagulating albumen. Coal tar contains a considerable quantity of creosote, and when boiled, to expel its ammonia, it is called coal oil. The proportion of creosote in this oil is ascertained by mixing it with 10 per cent. of its own bulk of a strong caustic alkaline solution. After shaking and settling, three layers will be formed, the lower layer of caustic alkali; the next being creosote; while the bituminous oils float at the top. In 1840 Mr. Bethell took out a patent for treating inferior animal and vegetable oils, by depositing the mucilaginous and gelatinous matter from them, and mixing them with light hydrocarbons, to obtain good lamp oils. In 1848 he devised a method of drying grain upon a system of endless cloths on revolving rollers; also a method of preserving meat by injecting pyroligneous acid, and afterwards common brine, into the arteries of a recently-killed beast; and besides these a mode of preserving milk or acid wines by impregnating them with carbonic acid gas. In 1853 he patented an improved method of retting flax by the aid of warm water; and in the following year a method of making coke from non-coking coal, by previously mixing it with from 20 to 25 per cent. of coal-tar pitch. In 1855 he patented a method of preserving meat, vegetables, and fruit by vapourizing the water contained in them, at a temperature lower than that required for the coagulation of albumen. In 1857 he took out a provisional specification for a method of building composite ships of T iron and wooden planks; and in the same year patented a steam plough, consisting of a rotary digger or excavator combined with a traction engine. In 1858 he patented a method of separating iron pyrites from coal, the former to be used in the making of vitriol; and he obtained a provisional specification for a method of protecting iron cylinders from the action of sulphate of copper and other salts used in preserving wood. In 1861 he patented the use of steatite in railway greases; and in 1864 a method of injecting timber with hydrocarbon vapours. Mr. Bethell also bestowed much labour upon

a plan for concentrating all the London gas-works at a site some miles down the river. He carried on for some time a distillery of beetroot spirit in Berkshire. He also effected considerable improvements in the extraction of copper from ores of low percentage.

Mr. Bethell was elected an Associate of the Institution of Civil Engineers on the 20th of March, 1838; and on the 24th of the following month read a Paper "On firing blasts under water by galvanism."[1] He was one of the Auditors of the Accounts in the years 1843 and 1844, and occasionally took part in the discussions at the evening meetings. He died, after a short illness, at his temporary residence, Cleveland Square, Hyde Park, on the 22nd of February, 1867, in his sixty-third year.

Mr. CHRISTOPHER JOSEPH CATO was one of the earliest settlers in Natal, and took an active part in the stirring events connected with the establishment of the British Government in that colony. He was in charge of the 'Mazeppa' when he took her out of the bay, under the fire of the Boers stationed on the Bluff and at the Point. By profession an architect and civil engineer, he frequently furnished plans for public works such as gaols, etc. His opinion was highly valued by the Colonial Government; and on one occasion when there was a diversity of opinion respecting the construction of the Natal Harbour Works, the soundness of his views was fully borne out.

Mr. Cato had great fondness for all nautical matters, and was the first commodore of the local yacht club. He also took a zealous interest in the establishment of the Volunteer corps, having been, first, major of the Durban Volunteer Guard, the first foot corps started in Natal, and subsequently lieut.-colonel of the Durban Rifle Guard, during the earlier years of its existence. Mr. Cato established the large steam flour and saw mill at the east end of the town of Durban, and took a personal and lively interest in all that concerned the welfare of the colony.

He was elected an Associate of the Institution of Civil Engineers on the 2nd of December, 1862, and died at his residence, Mount Vernon, Berea, Port Natal, on the 20th of March, 1867, aged fifty-one years.

Mr. EDWARD MAGDELEN JOSEPH DELANEY was born in Newfoundland on the 21st of July, 1836. His father held a seat in the Legislative Assembly, and filled the office of Postmaster-General for several years.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), p. 35.

At an early age he showed a taste for the study of surveying and engineering; and after having acquired a sound knowledge of mathematics and surveying, was admitted a pupil in the Surveyor-General's office, under the Honourable Joseph Noad.

After passing some time there, devoted to his favourite pursuits, he came to England and entered as a student in the Department of the Applied Sciences at King's College, London, where he remained during the years 1857 and 1858, and distinguished himself very creditably, receiving high testimonials of his proficiency from the several Professors.

On his return to his native place, he was immediately appointed principal Surveyor and Engineer in the office of the Surveyor-General, where his bland and obliging disposition won the esteem and confidence, as well of the public generally as of the Government under whom he served.

In the month of August, 1866, he was sent into the interior of the country, for the purpose of laying out agricultural settlements, where, from the fatigue and exposure attendant upon such operations in an uninhabited region, his health was undermined, and shortly after he contracted a cold, from the effects of which he never recovered.

Mr. Delaney was Meteorological Observer in Newfoundland, for the Smithsonian Institution at Washington, for several years. During his brief career, the only engineering opportunity that offered, arose from the long-felt necessity of removing a serious obstruction that rendered the little but useful harbour of Quidi Vidré almost useless. This impediment consisted of several large rocks, rising near the surface. Mr. Delaney directed their removal; and this work was accomplished, without a single accident, in two years.

Mr. Delaney joined the Volunteer force immediately on its enrolment, and was shortly after Gazetted Ensign and Lieutenant: he was greatly esteemed by his corps, and the whole Volunteer force followed his remains to the grave, and gave him military honours at his last resting-place. He was elected an Associate of the Institution of Civil Engineers on the 5th of March, 1861; and died at St. John's, Newfoundland, on the 11th of December, 1866.

Captain MARK HUISH was descended from an old Leicestershire family. He entered the East India Company's service at an early age, and obtained rapid promotion. Returning from India, he became Secretary and General Manager of the Glasgow and Greenock Railway, shortly after its opening in 1839 or 1840; and was Secretary and Manager to the Grand Junction Railway Com-

pany from 1841 to 1845. In this year the Grand Junction Railway Company was amalgamated with the Liverpool and Manchester and Bolton Railway Company, and Captain Huish was appointed manager of the united companies. During the memorable gauge contest of 1845—46, in which he took an active part, the Grand Junction sought an independent line to London—an attempt which led to its amalgamation, in 1846, with the London and Birmingham Railway. The fusion of these companies into one undertaking—the London and North Western—was in a measure due to the personal influence of Captain Huish, and he became the general manager of the whole line. His rule was based on sound commercial principles, as well as upon an admirable system of centralization; and he was a zealous and determined upholder of the interests of the Company with which he was connected. He enforced the utmost responsibility everywhere, and succeeded by this and other means in securing regularity, safety, and celerity in railway travelling, and a command over sudden and overwhelming eruptions of traffic. In September, 1858, Captain Huish resigned his post, in consequence of the course taken by the leading representatives of the competing lines with which the London and North Western Board had to carry out traffic arrangements. After the final acceptance of his resignation, in November, 1858, he was presented with an address, and testimonial from upwards of five thousand persons in the employ of the Company. During the entire period of his connection with the Company, Captain Huish exercised an important influence over its councils, and the undertaking continued to increase by the absorption of other lines, and the construction of additional branches. In 1846 the capital was £16,000,000, and the revenue £2,000,000; and in 1858, the capital was £25,000,000, and the revenue £3,000,000. The advice and opinion of Captain Huish, owing to his ability and experience, were frequently sought by those connected with other companies, and his influence generally was felt and admitted by the entire body of railway managers. Captain Huish was Chairman of the Clifton Suspension Bridge Company, Deputy-Chairman of the Electric and International Telegraph Company, and a Director of the Isle of Wight Railway Company, of which he was the main supporter. He also took a warm interest in the introduction of the pneumatic system of railways.

On retiring from the management of the London and North Western Railway, Captain Huish took up his permanent residence at Combe Wood, near Bonchurch, in the Isle of Wight. He joined the Ventnor Rifle Corps as a private, and was a staunch supporter of the volunteer movement. At the earnest solicitation and unanimous voice of the corps, he, a few months before his death, accepted

the command of the Company, and by the heartiness with which he set to work, raised it to a considerable degree of efficiency.

And if in business and public matters Captain Huish's name was so well known, so in moral and benevolent movements was he a foremost man. He was especially an active supporter of the London City Mission, and was always ready to advocate its claims. Other benevolent objects also had his hearty co-operation; and his house was often thrown open for religious meetings, and for the reception of various societies with which he was connected.

Captain Huish was elected an Associate of the Institution of Civil Engineers on the 6th of April, 1852; and served as an Associate of Council in 1859—60. Shortly after his election he presented a Paper to the Institution on "Railway Accidents; their Cause, and means of Prevention; detailing particularly the various contrivances which are in use, and have been proposed."[1] He died, after a short illness, on the 18th of January, 1867, aged fifty-eight years; and was interred in the parish church of Bonchurch.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 434.

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